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A STUDY TO IDENTIFY AND COMPARE AIRBORNE SYSTEMS FOR IN-SITU MEASURMENTS OF LAUNCH VEHICLE EFFLUENTS

by

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Battelle
Columbus Laboratories

FINAL REPORT

on

A STUDY TO IDENTIFY AND COMPARE AIRBORNE SYSTEMS FOR IN-SITU MEASUREMENTS OF LAUNCH VEHICLE EFFLUENTS

to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER

October 31, 1974

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Executive Summary

The study reported herein was directed at two objectives. The primary objective was to compare airborne systems for in-situ monitoring of solid propellant launch vehicle exhaust clouds, while the secondary objective was to broaden the monitoring scope to urban atmospheres.

In the primary study, the exact nature of the problem is first delineated, and the elements of the in-situ system are identified. Following this, more detailed discussions on the system elements and their capabilities, features, and options are presented.

Primary attention is given to the platform and instrumentation elements, as they are the driving members of the overall system. Other system elements are discussed in less detail. Operational constraints are also presented, as well as a discussion of the chemical complexity of the exhaust cloud.

Selection of optimal components does not, in general, produce an optimal system. The approach of this study was to devise from internally compatible and operationally consistent systems, one for each major platform. These four systems are presented in some detail, and the trade-offs that compromise them are discussed. A ranking scheme was used to select the best system of the four. The final trade-offs for this best system are discussed, and the details of it are completed.

A slightly different approach is followed for the secondary objective. After a statement of the problem, the perceived instrumentation needs are used to reduce the options, by first considering required instrument ranges and second, response time.

After the instrumentation options are reduced, final selection of instruments is straightforward. Selection of platform and supporting instrumentation is also straightforward.

ABSTRACT

The study reported herein had as its primary goal the recommendation of an in-situ system for monitoring the concentration of HCl, CO, CO_2, and Al_2O_3 in the cloud of reaction products that form as a result of a launch of solid propellant launch vehicle. A wide array of instrumentation and platforms are reviewed in the context of the goal: from this review a methodological approach yields a recommended system.

The information obtained during the study of the primary goal was used in the secondary goal, that of selecting an airborne system best suited to monitoring pollution concentrations over urban areas for the purpose of calibrating remote sensors. A methodology similar to that of the primary goal is applied to yield the optimal configuration for the secondary goal.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF FIGURES

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THE PRIMARY MISSION

The primary purpose of the study contained herein is the investigation of alternative airborne systems for carrying instrumentation which measures the launch vehicle effluent concentration and distribution within the stabilized ground cloud with the objective of recommending one system for actual operation. In order to recommend such a system, it is necessary to understand the features of the ground cloud and the constraints of operations offered by the existence and operations of the Eastern Test Range, Patrick Air Force Base, and other agencies.

The recommended configuration will be that which best meets design objectives and operational constraints while capitalizing on the existence of support equipment already at the Eastern Test Range. In order to explore the alternatives available to the selection process, it is desirable to review, in a general context, the factors which will affect the selection. Figure 1 presents the interrelationships of system components, the cloud, and the constraints.

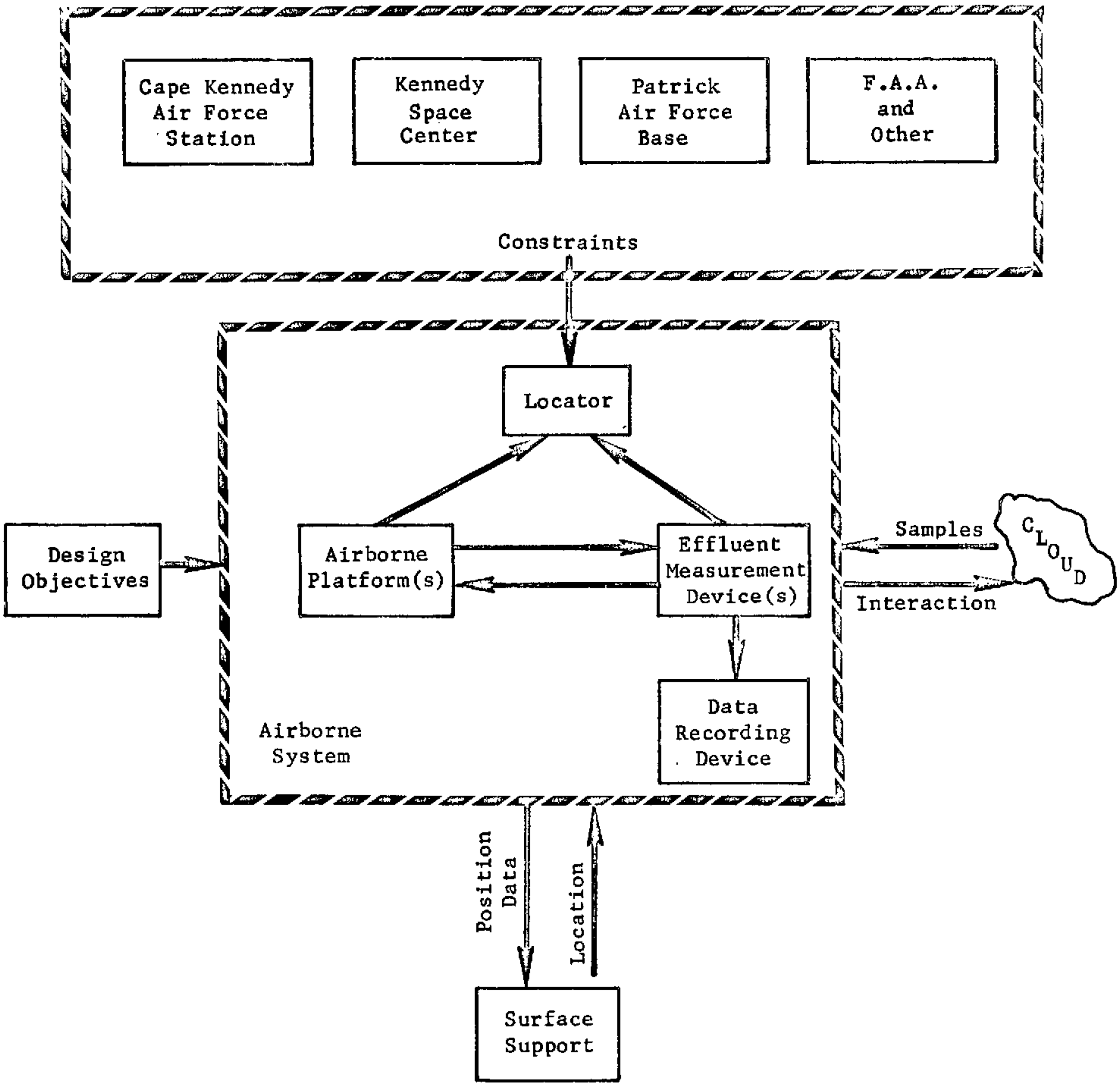

FIGURE 1. IN-SITU EFFLUENT MEASUREMENT SYSTEM

The Ground Cloud

The ground cloud forms as a result of thermal buoyancy acting upon the great mass of launch vehicle exhaust reflected from the ground during the early vehicle motor operation. The vehicle effluent rises and stabilizes at an altitude where the cloud density is the same as the atmospheric density. The ground cloud could conceivably have several centroids representing various constituents.

The cloud stabilizes as early as two minutes after launch at an altitude of 200-2200 meters, with a relationship between altitude and time, Typical values for the stabilization are closer to 4 minutes and 1300 meters.

The stabilized ground cloud from a Titan IIIC has initial characteristic dimensions which approach 500 meters. As the cloud is being transported away from the launch site due to local winds, it is also dispersing due to turbulence and molecular diffusivity. During the 1-hour period for which samples are to be taken, the cloud will move typically 14 km, but this study is directed only at the first 6 km.

The direction of the cloud drift is determined by the local winds, and can be inaccurately predicted in advance(1). The 6-km drift could place the cloud over the Atlantic Ocean, the Merritt Island Wildlife Refuge, or within the Patrick Air Force Base controlled airspace(a). Figure 2 displays the potential drift of the cloud.

Initial concentrations of chemicals within the cloud depend upon many variables, among them being the quantity and type of fuel consumed. Two specific rockets are considered here, the Titan IIIC and the Delta, as each has a solid fuel rocket motor.

The chemicals of interest, namely CO, CO_2, HCl, and Al_2O_3, will have peak initial concentrations of around 500 ppm (gases) or 500 mg/m^3 (Al_2O_3). Concentrations after 1 hour should diminish by a factor of 100.

Chemical reactions within the cloud may be evident in observed concentrations(2). The high water vapor content of the rocket exhaust will cause the formation of liquid aerosols, which will absorb HCl to

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(a) From 1974 Jacksonville Sectional Aeronautical Chart.

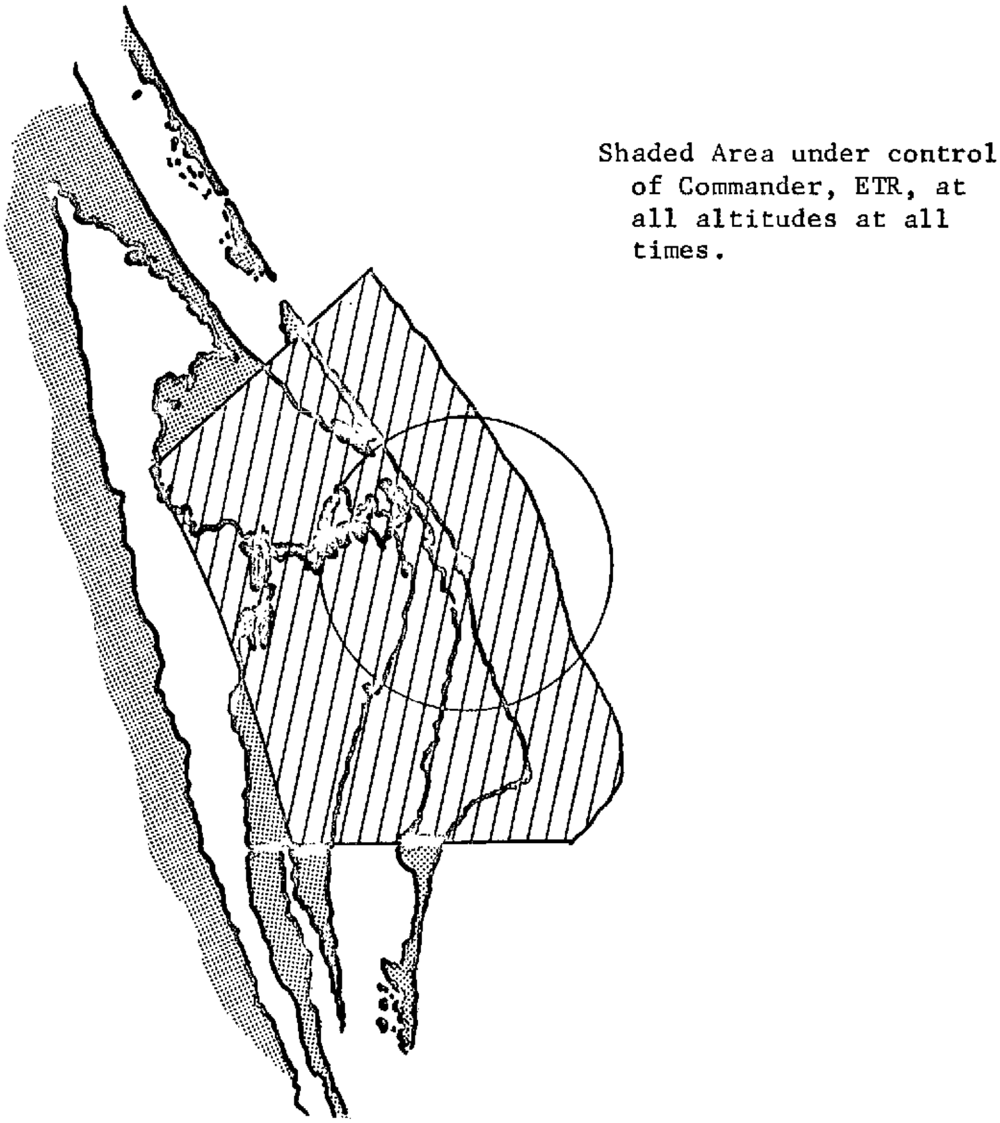

FIGURE 2A. INTERSECTION OF MISSION RADIUS
WITH EASTERN TEST RANGE CONSTRAINT

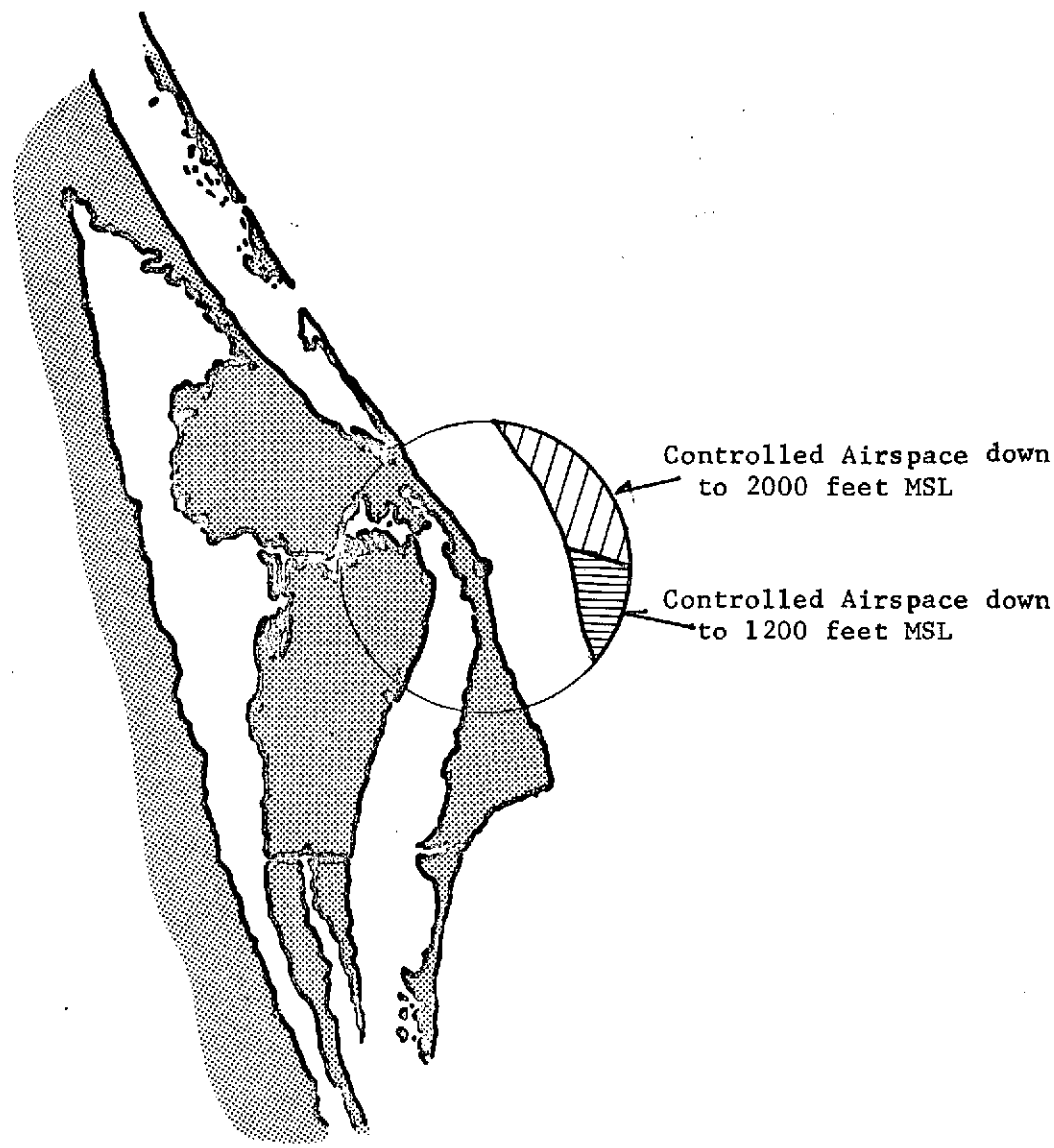

FIGURE 2B. INTERSECTION OF MISSION RADIUS WITH MIAMI ARTC CONTROLLED AIRSPACE

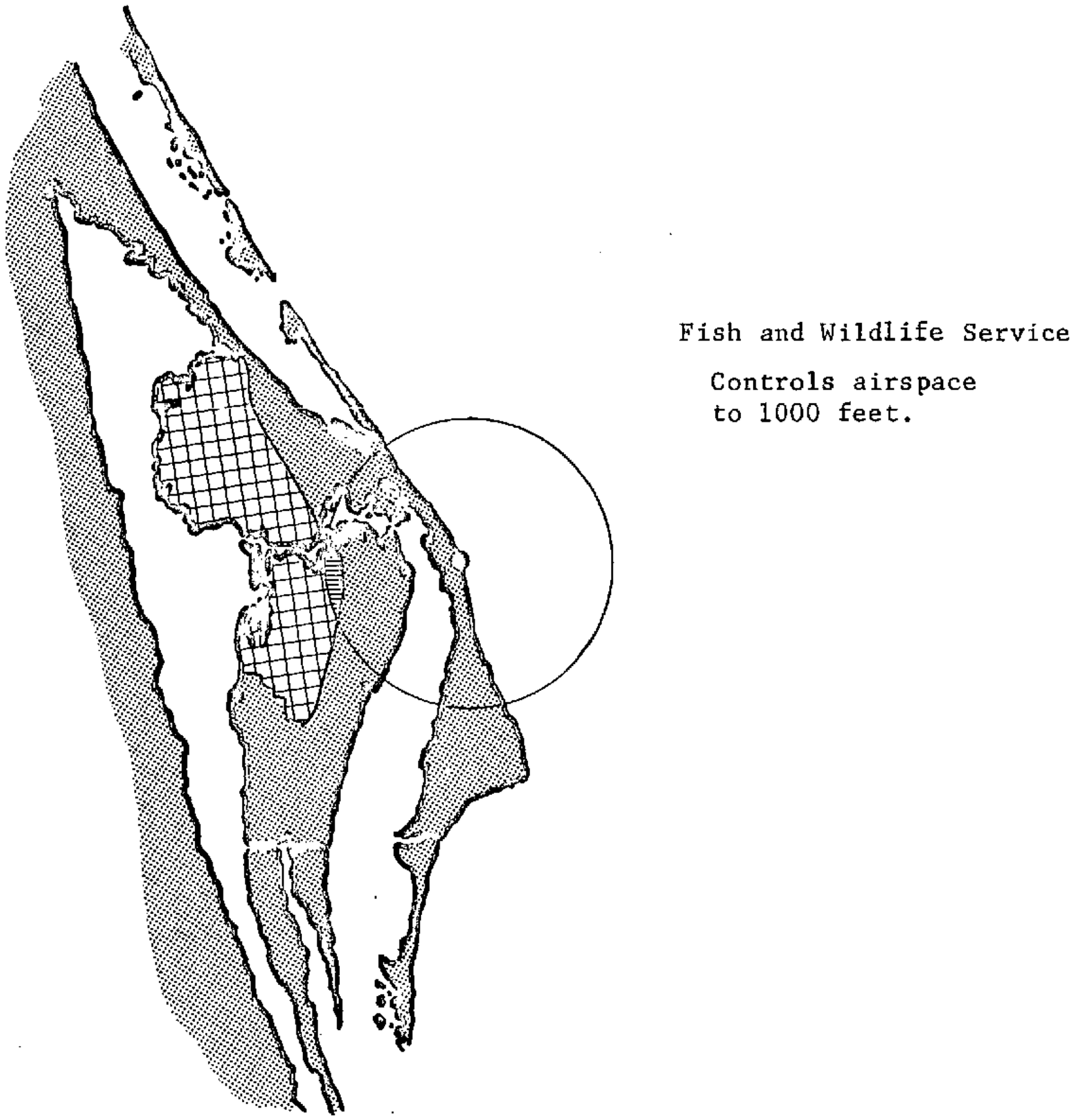

FIGURE 2C. INTERSECTION OF MISSION
RADIUS WITH WILDFILE REFUGE

form a strong acid mist. The Al_2O_3 will have a γ crystal structure,[3] hence, some will dissolve in the aerosol. In addition, the particulate Al_2O_3 is an excellent absorber of water vapor, and with a large surface-to-volume ratio, will hydrolyze rapidly with 1, 2, or 3 molecules of water vapor. The carbon monoxide will oxidize to carbon dioxide, with upwards of 80 percent of the carbon monoxide so transformed.

After the cloud has drifted for some time, the cloud effluents disperse. The ground level concentrations are highly dependent upon the vertical dispersion rate. Thus, it is desirable to quantify the vertical distribution of the concentration as a function of time.

The cloud to be sampled is essentially a puff of smoke. The measurement procedure will be repetitive sampling from this puff. To obtain meaningful results, it is necessary to avoid to the maximum extent possible, the mechanical or chemical distrubance of the cloud.

The cloud is initially quite visible in the day time and can be observed for approximately 1 hour. On clear nights, visual tracking can follow the cloud for around 20 minutes. IR tracking can follow the cloud for 1 hour either day or night.

In order to relate the measurements to the cloud, it will be necessary to know the relative location of the measurement instrumentation to the cloud. This may be done by monitoring by radar the location of the instrumentation, and by cinetheodolite or IR imagery the centroid of the cloud.

Candidate Sensing Platforms

In the following discussion, candidate platform systems are evaluated relative to their ability to perform the required mission. These platforms, and/or systems, and their major performance characteristics are first briefly summarized.

(1) <u>Powered, Fixed-Wing, Manned Aircraft Flying Through the Cloud</u>

Applicability--A low cost, reliable system could be readily assembled with off-the-shelf hardware. A life-support system would be required. Simultaneous measurements would be possible but difficult.

Velocity--Aircraft with low-wing loading would achieve a minimal velocity and disturbance when in the cloud. Minimum velocities of 100 to 110 km/hr could be achieved.

Payload--Weight is unlimited, but packaging could be a problem.

Cloud Disturbance--Disturbance of the cloud will be substantial, especially for larger payloads. Also, some effluence will be added to the cloud. (For first order estimate see discussion in text on helicopter cloud disturbance).

(2) <u>Manned Gliders Flying Through the Cloud</u> (unpowered, fixed-wing manned aircraft)

Applicability--Although appropriate, gliders are less available than powered aircraft. The cost of a basic off-the-shelf glider is approximately 8 to 9 thousand dollars. Such a glider can carry one passenger and a payload of 180 kg. A sink rate of .76 m/sec can be achieved with minimal forward speed of 80 km/hr. Such planes can withstand ±8 g's, with special effort, ±9 g's can be achieved. A top-of-the-line glider, such as the Schweizer 2-32 sailplane, costs $18,000(4). Utility payloads go to 260 kg. A specially designed powered glider would cost about $150,000 to $200,000(5). A standard life support system suitable for bailing out are available. Simultaneous measurements of the cloud would be difficult.

Velocity--Conventional US gliders would require towing to the target. Maximum tow velocity is about 240 km/hr

After passing through the cloud, the glider would probably have to maneuver to increase its elevation before the next pass. Powered gliders have not been certified by the FAA. All off-the-shelf powered gliders are built in Germany or other foreign countries. Three special purpose powered gliders have been built by Schweitzer Aircraft Company for Lockeed, Martin, and LTV. The Martin and LTV systems are remotely controlled.

Payload--About 120 to 260 kg maximum including pilot. Packaging problems may develop.

Cloud Disturbance--Probably not substantial for gliders.

Note--Turbulence within the cloud may affect small gliders.

(3) Manned Rotating Wing Aircraft Flying Through the Cloud.

Applicability--A low-cost, reliable system could be readily assembled with off-the-shelf hardware. A life support system would be required. Simultaneous measurements would be difficult.

Velocity--All desired velocities are achievable.

Payload--Weight is unlimited, but packaging problems may develop.

Cloud Disturbance--Disturbance of the cloud will be substantial, especially for large payloads (see following text for details). Considerable effluence would also be added to the cloud.

Note--Turbulence within the cloud may affect aircraft, but preliminary data does not support this hypothesis.

(4) Remotely Piloted Vehicles (RPV) Flying Through Cloud.

Applicability--Appropriate but availability limited. Control problems may be difficult and expensive. The Mini-Sniffer appears to be the best RPV for this mission. Simultaneous sampling would be difficult.

Velocity--From 75 to 220 km/hr for Mini RPV's; large RPV's from 185 to 740 km/hr. Minimum velocity of mini-sniffer is 56 km/hr, wing loading 4.9 kg/m^2, turning radius 660 m, climb rate 14 m/sec at 1500 m.

Payload--Seventy pounds for the Mini-Sniffer at an elevation of 1500 m. Instrumentation packages to monitor the atmosphere are being developed(6). Several thousand pounds can be carried by large RPV's. Packaging problems may develop.

Cloud Disturbances--Small disturbance of the cloud is expected for small RPV's such as the Mini-Sniffer. Also, a small amount of effluence would be added to the cloud. Cloud disturbance will be greater with large RPV's.

Note--Turbulence within the cloud may affect Mini-RPV's.

(5) Slow Descent Devices Dropped Through the Cloud (i.e., parachutes, ballutes, small balloons).

Applicability--Reliable, low cost, slow descent devices are available or could be specially built. An aircraft or helicopter would be required to deploy the system, accurate positioning has been demonstrated. Simultaneous measurements would be possible, but the sensor's location once within the cloud cannot be controlled. It is crudely estimated that 50 to 100 ballutes could be built within 6-8 weeks at a cost under \$100,000(7).

Velocity- Descent rates of 1.25 m/sec can be expected. A descent rate of 1 m/sec is pushing the state of the the art. Payload will move with the cloud in the horizontal plane(7).

Payload--Size and weight are unlimited. An instrumentation package will be required each time the cloud is sampled. Mid-air recovery has been demonstrated with "quite high" success ratio. Safety problem when cloud is overland.

Cloud Disturbance--Very small.

(6) Rotating Wing Aircraft Flying Above Cloud and Supporting a Suspended Payload which is Positioned within the Cloud.

Applicability--A moderately low cost, reliable system could be assembled with off-the-shelf hardware.

Velocity--Helicopter would probably not be able to travel to the cloud at high speeds (i.e., much above 75 km/hr) if the payload were suspended on a long cable. Loads are likely to be neutrally stable sometimes spinning. At night pilots have more difficulty in stabilizing the load than during the day. A payload stabilization system may help. Sikorsky Helicopter Company has done some work on load stabilization[8].

Payload--Essentially unlimited. Payload must be suspended on very long cables (i.e., at least 1000 ft) to minimize cloud disturbance or, payload could be suspended between two helicopters with a horizontal separation, as in Figure 3.

Cloud Disturbance--The magnitude of the cloud disturbance is dependent upon the height of the helicopter above the cloud, hovering time, and weight of helicopter plus payload. Substantial disturbance may develop as noted in the following text.

(7) Fixed-Wing or Rotating-Wing Aircraft with Circling Line.

Applicability--A low cost, readily available system. However, the approach is very high risk and should be demonstrated before the test.

Velocity--High velocity may cause instability of payload.

Payload--Large loads can probably be used. It may require packaging in an aerodynamic configuration. Position of payload within the cloud will be difficult to control.

Cloud Disturbance--Probably moderate.

(8) Large, Towed Balloons (including hot air, helium filled, tethered and free flight).

Applicability--Few large balloons are operational. Moderately high costs can be expected (because of ground support). Platform has not been adequately demonstrated for this purpose and is somewhat unreliable.

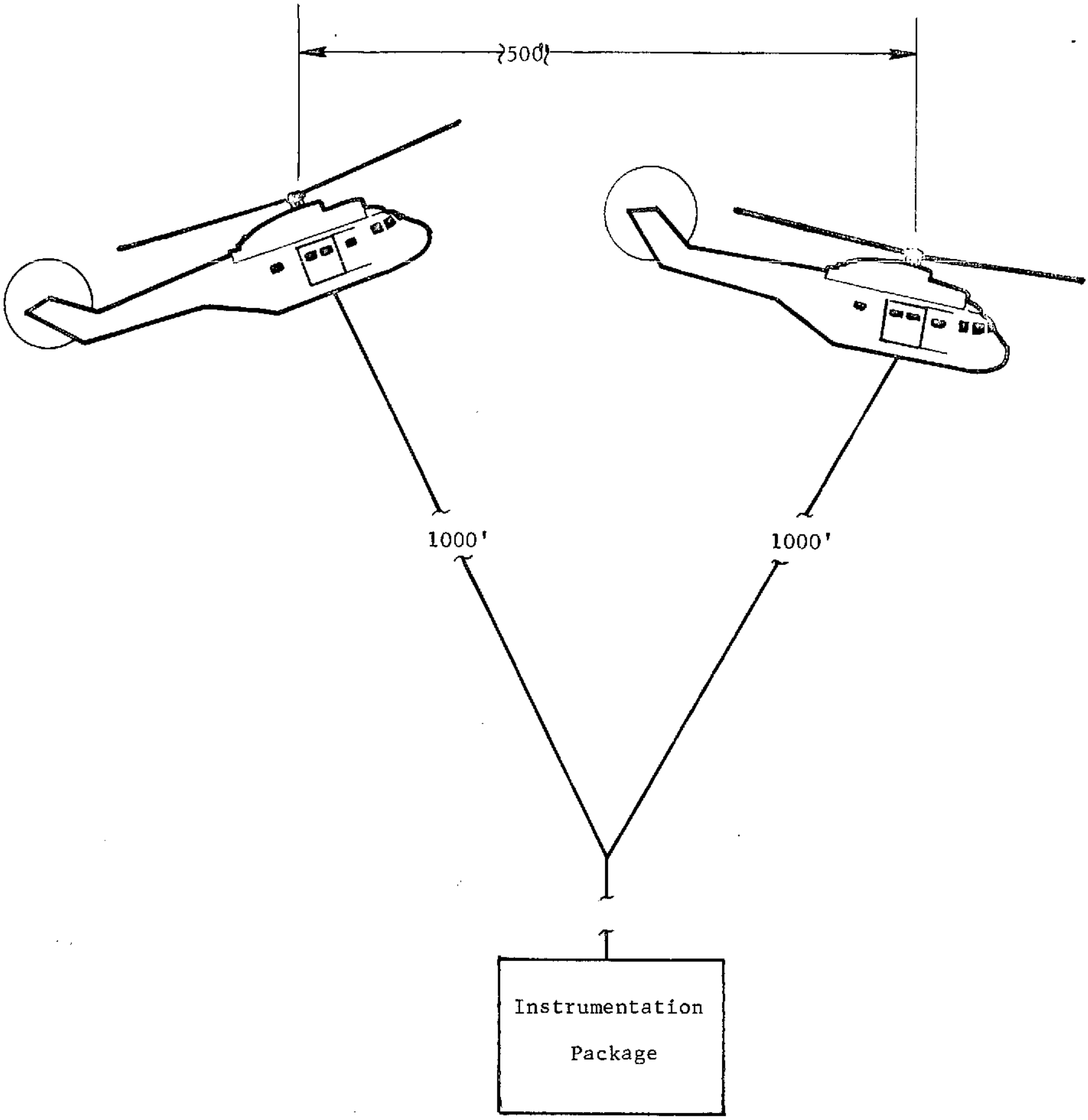

FIGURE 3. POSSIBLE HELICOPTER TOWING CONFIGURATION WHICH MINIMIZES CLOUD DISTURBANCES

Velocity--An ARPA Family II "tethered" balloon has been towed on two occasions at 83 and 120 km/hr. This is an aerodynamically shaped balloon. Natural shaped balloons become unstable unless they are towed at substantially lower speeds. Consequently, natural shaped balloons will probably not be able to reach the cloud within four minutes after launch. Although they will drift with the cloud, they will be difficult to control for small displacements when towed(9).

Payload--Unlimited if large enough balloon is available.

Cloud Disturbance--Minimal.

(9) Blimps (powered, manned lighter-than-air aircraft)

Availability--Goodyear owns and operates the only candidate system in the U.S. It would be expensive to rent ($175,000 to $200,000 per month). A no cost loan of the system may be possible for a few days. However, it is unlikely that Goodyear would allow their blimp to be used on this program because of potential damage to balloon system and personnel. Maximum ceiling 1500 m(10).

Velocity--80 km/hr maximum. Acceleration, to 75 km/hr in 30-40 sec. Acceleration greater than 1/2 g has never been measured while in flight. Station-keeping ability within a few feet.

Payload--320 to 1815 kg. Payload must be suspended since Goodyear will not allow balloon fabric to come in contact with the cloud.

Cloud Disturbance--Very little.

Deployment of the sensor includes its transportation from a ground or airborne station to a position suitable for in-situ monitoring of the cloud (effluent) formed by the rocket exhaust. Candidates for transporting the sensor include the following platforms: helicopters, fixed-wing aircraft, sailplanes, RPV's, parachutes, blimps, and balloons. It is desirable to begin monitoring the cloud as soon as the cloud reaches a stable position. The total movement of the platform is primarily dependent upon the drift rate of the cloud and the position of the platform prior to launch. The capability of various sensor platforms to meet these criteria without damage to the payload is a major factor in determining these criteria without damage to the payload is a major factor in determining the best suited platform.

A typical scenario must first be selected so that the capabilities of candidate platforms can be compared against mission requirements. Noting the last section, it is assumed that the sensor must deploy the instrumentation within the cloud 4 minutes after missile launch, and that the platform cannot move from its station-keeping position for the first minute following launch. The time for the platform to reach the cloud is, therefore, 3 minutes. The platform is also assumed to be initially stationed 3200 meters from the estimated positinn of the cloud. The assumed position and time imply that the platform's average velocity to the cloud must be 65 km/hr. Many cases may exist where the required velocity is greater than this typical case.

Most helicopters and fixed-wing aircraft can travel at these velocities. Sailplanes such as the Schweizer 2-32 can be towed at a maximum velocity of 240 km/hr, and so many sailplanes also have the capability to reach the cloud within 3 minutes. Tethered balloons would, of course, remain stationary, and so, they are unsatisfactory to perform the required task. However, one version of the ARPA Family II balloon has been towed at 125 km/hr. Currently, there are three blimps (powered, nonrigid airships) in the U.S. of sufficient size for this experiment: Goodyear owns and operates all three for advertising purposes. These blimps can achieve a maximum velocity relative to the local wind of 80 km/hr[10], and so they have marginal capability. Natural-shape balloons have an even greater drag than do blimps, which are aerodynamically-shaped structures. Consequently, the maximum velocity of a powered, natural-shaped balloon is expected to be considerably less than the maximum velocity of the Goodyear blimps.

Many platforms can travel at the required average velocities. However, the more time it takes for the platform to become airborne, and for the sensor to be deployed, the less time available to fly to the cloud.

The required flight velocity may, therefore, be considerably greater than the average. For example, if it takes 3 minutes for a helicopter to lift the tow line and sensors off the ground in a configuration suitable for sensing, then the helicopter must travel to the cloud in 1 minute at an average velocity of 195 km/hr.

Because of the requirement that the platform reach the cloud within 3 minutes, it may be necessary for the platform to be airborne when the missile is fired. Fortunately, the launch windows are small enough so that a hold in the countdown sequence will probably not require an airborne platform to return to base for refueling.

The method of carrying the sensor affects the maximum instantaneous velocity capability of the platform. For example, when the payload is carried within the platform, then the payload only influences flight performance characteristics through the gross weight and center of gravity parameter. No major technical problems are likely to occur in this case. However, when the payload is towed or carried externally to the platform, then aerodynamic drag forces and load instability become additional factors affecting the payload's maximum velocity.

Reference 43 provides some insight into the stability problems that can arise when towing a payload on cables suspended from a platform.

> "In the past few years, airborne towing has proven to be very useful for industrial and military transportation. Even though this means of transportation has demonstrated its effectiveness, reports have revealed that quite often serious instabilities have occurred. Asseo and Erickson[11] mention the dangerous load oscillations experienced while towing low density, high drag loads, which have resulted in emergency load jettison and some load/helicopter collisions. Similarly, Etkin and Mackworth[12] report of serious instabilities which occurred while transporting loads of dense material in a specially designed bucket. Experimental investigations by Shanks[13-15] showed that lateral instability may arise in towing parawing gliders and half-cone reentry vehicles. These problems have resulted in a number of investigations to determine the criteria necessary to ensure stability during airborne towing."

"In a recent paper by Poli and Cromack[16], it is shown that long cables, high speeds, and light loads are required for the stability of a slung load using a single-point suspension system. The drag-to-weight ratio of the towed body and the cable length were shown to be the most important stability parameters. The towed body analyzed was an 8 x 8 x 20 ft cargo container. Cable lengths required for stability were found to range in excess of 800 ft at a drag-to-weight ratio of 0.01 to about 100 ft at a drag-to-weight ratio of 0.1."

"Szustak and Jenny[17] discussed the use of multicable suspension systems. They showed that for the two and four-point suspension systems, short cables, low speeds and heavy loads are required for stability. It should be noted that these results are opposite to those obtained for a single-point suspension system, the reason being that for a single-point system, it is mainly the drag force that aids in stability, whereas for the multi-point system, it is the restoring moment of the cables which provides the stabilizing effect."

The size and weight of the towed load referred to in these quotes is larger than required for the cloud monitoring task. Nevertheless, these quotes illustrate that some seemingly simple external load handling problems are in fact difficult to solve. This point has also been made in other sources. It is also noted that almost all loads can be carried within the helicopter lift capability if the operator is willing to compensate his operations enough. These compensations would require operations at reduced speeds, the use of slings and/or rigging with auxiliary stabilizers or drogue chutes[18-20]

In the final analysis, the need to stabilize the load is dependent upon the potential damage to the platform and instrumentation. The instrumentation, however, will usually be rugged since it can generally withstand "g" loads which are experienced when transporting equipment cross country in a trailer.

Safe operational speed for towing conventional loads with a helicopter is 110 km/sec[21]. Therefore, it can be expected that no major stability problems will arise if the payload is only carried at 65 km/hr (as assumed in the typical scenario). At greater speeds, an increased uncertainty exists, especially if the load being towed is in an unusual configuration. Examples of unusual configurations include an instrumentation package being towed on a 305 m tow line. Wind tunnel or actual flight tests are recommended for such cases.

One possible concept of sensor deployment involves a circling line towed behind a fixed-wing aircraft. With this concept, the payload is lowered into the cloud as the airplane maneuvers above the cloud in smaller and smaller circles. The stability of the payload is a major unanswered question. Complete analysis and testing of the concept would require a considerable effort, and so the circling line is not recommended.

To complete this discussion, it is briefly noted that some attempts have been made to actively stabilize slung loads. Of primary importance is a prototype stabilization system which has been built by the Sikorsky Helicopter Division of the United Aircraft Corporation. This system modifies the autopilot control signals as a function of the angle of the tow cable as measured within 1 degree at the point where it attaches to the helicopter. In this mechanization, the helicopter is forced to undergo small displacements from a nominal flight path so that the payload does not undergo long-period oscillations[18,21].

Asseo and Erickson attempted to show the feasibility of using winches as active controls for load stabilization[11]. They proposed a three-point suspension system consisting of longitudinal and laterally displaced cables driven by vertical winches placed at the bottom of the helicopter structure. The front helicopter cable attachment was capable of being laterally displaced relative to the helicopter. Various cable lengths and cargo orientations could thus be obtained so that stability could be assured. The major problem with this system appeared to be the complexity of the control system.

In another study, aerodynamic fins have been shown to stabilize the payload and therefore permit a reduction in the cable length. Reaction wheels mounted on the payload have also been suggested.

Station Keeping

After the platform has been moved to the cloud, it must support the sensors for a 1-hour period while a series of tests are being performed. During each of these tests, the platform is required to hold the position of the sensors fixed within the cloud for a period of up to 1 minute. The results of this experiment must not be affected by cloud disturbances caused by the platform. The cloud is expected to stabilize at altitudes less than 3000 meters, a typical value being 1300 meters.

If the sensor platforms were required to remain over a low flying cloud for 1 hour while supporting about 455 kg payload, then small helicopters have the capability to perform the required task. For example, the UH-1F can hover at 1300 meters with a total weight of fuel, payload and crew equal to 2000 kg. With 910 kg allowed for fuel and a crew of two, a 455-kg instrumentation package designed to monitor the cloud is a realistic load. The fuel is sufficient to permit 1-1/2 hour flights. However, mission requirements are a 3000-meter (about 10,000 ft) elevation, also, the helicopter may be required to hover for several minutes while waiting for the rocket to be fired. At 3000 m, the UH-1F can only hover with a weight of fuel, payload and crew totaling 295 kg. These conditions effectively eliminate the use of small helicopters from performing the required mission when the cloud rises to very high altitudes[(22)].

Helicopters such as the CH-47A remain good candidates to perform this task. The CH-47A can support a total weight of 5,450 kg of fuel, crew, and payload at 3000 m, and 7,730 kg at 1500 m. When empty, the CH-47A weighs 8200 m[(22)].

A somewhat larger helicopter is the HH-53B, which weighs 10,510 kg when empty, and has a maximum takeoff weight of 19,100 kg. This helicopter is also a candidate for sensor platform, although it has more capability than needed. It is primarily mentioned here because of its use during a test program designed to measure the modification of cloud structures by helicopter wakes. These tests were performed in 1968 at Eglin AFB, Florida, and the resultant data provides valuable insight into cloud formed by missile exhaust[(23)].

During this study, a model of the downwash velocity profile from the HH-53B helicopter was constructed and verified. Velocities were 30 m/sec near the rotor, and decreased to negligible values of a few feet per second at 400 m below the helicopter (see Figure 4). When

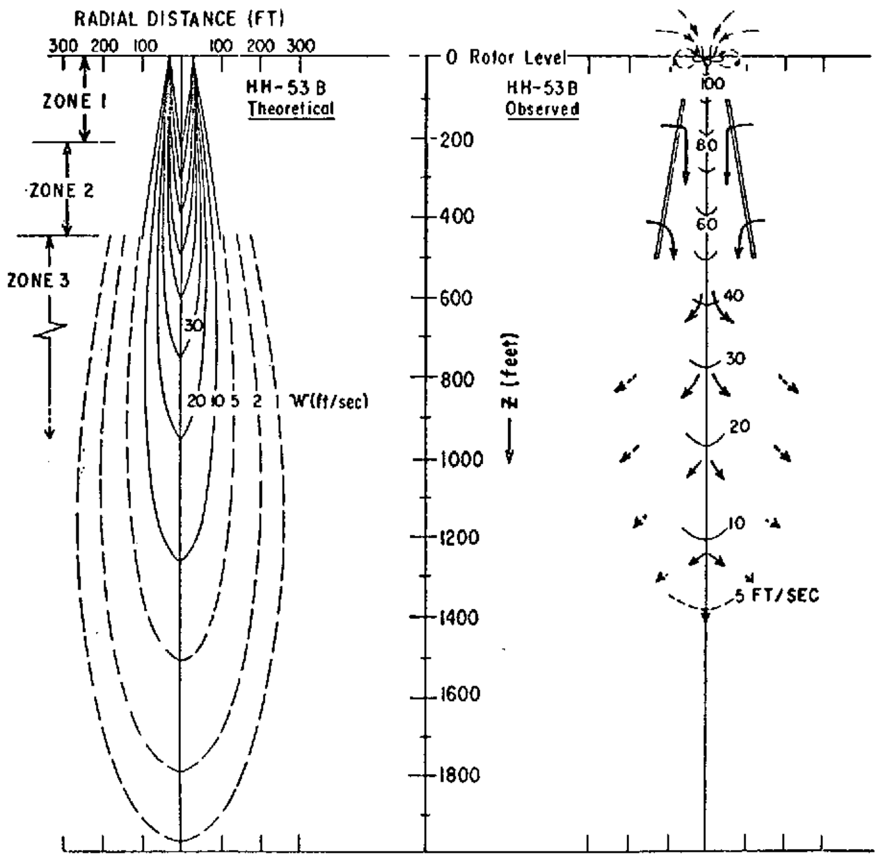

FIGURE 4. THEORETICAL AND OBSERVED CHARACTERISTICS OF THE DOWNWASH WAKE OF THE HH-53B HELICOPTER

Isotachs of downwash velocity prescribed by Hohler's equations are shown at the left. The downwash velocities and flow vectors deduced from the Eglin AFB observations are shown at the right[23].

hovering over clouds for a few minutes, this air stream was observed to create troughs and holes in the cloud with dimensions several hundred feet across. The stability characteristics of the air underlying the helicopter will, of course, have some affect upon the magnitude of the observed disturbance.

Reference 22 also notes that during this experiment, 5000 m^3 of air was thrust downward per second, which heated the air immediately below the helicopter by about 0.85 C. Under standard atmospheric conditions, this temperature increase serves to decrease the relative humidity by about five percent.

Exhaust fumes from the helicopter were also carried downward by the wake. The helicopter engine was about 30 percent efficient; consuming 0.34 kg/sec of JP-4.

Another factor which may alter the cloud's chemistry is that the combustion of the JP fuel produces 1.27 kg of water per kg of fuel burned. This water, when added to the wake air, was reported to increase the relative humidity by 0.3 percent(22).

Another source reported on the use of helicopter wakes to clear ground fog. It is reported that fog 300 m below the aircraft can sometimes be penetrated by cargo helicopters. A utility helicopter can penetrate a 100-m cloud(24).

Because a helicopter's wake can disturb the cloud, it may be necessary to either suspend the instrumentation package on a very long line, or to suspend the package from two helicopters as shown in Figure 3. In either case, such long cables will result in long-period oscillations of the payload. If these oscillations prove to be undesirable, the payload might be stabilized, as previously discussed.

A blimp, when a good pilot is at the controls, has excellent position keeping capabilities, which is at least comparable to that of a helicopter. Goodyear has the only operational blimps in this country. These blimps can only achieve an altitude of 1,525 m because their ballonet becomes fully inflated at this altitude. Blimps are, therefore, not capable of monitoring clouds which rise to higher altitudes. Other prohibiting factors include

- A rental fee of $175,000 to $200,000 per month. Even at these prices, the blimp cannot be rented for extended periods during the summer, spring and early fall, because these are prime advertising seasons.
- The required proof that the toxic fumes in the cloud will provide absolutely no danger to the crew, balloon fabric, engine, etc.
- A limited payload of 320 kg, plus a crew of two. If all advertising signs were removed from the blimp, a 1,820 kg payload is possible[10].

The tethered ARPA Family II balloons have the capability to carry 640 kg of payload at 3000 m. This weight includes the net weight of the power supply. There are no movable control surfaces on this balloon, and so it can only be properly positioned by towing[9].

To date, only one method of towing tethered balloons has been demonstrated. With this method, a large weight was suspended between the helicopter and balloon as shown in Figure 5. If this configuration were used to monitor the cloud, the balloon and helicopter would be pulled together by the resultant force of the suspended weight. This unacceptable condition does not occur when the balloon is towed at high speeds relative to the local wind, because large drag forces are developed on the balloon. Other methods of pulling the balloon have very high risk, and so they are also rejected for this program.

Powered, natural-shaped balloons are therefore the only lighter-than-air platform that offers the capability to remain suspended over a cloud during the tests. As previously mentioned, however, a major problem exists in initially positioning the balloon.

The payload could be dropped from an aircraft with small balloons, parachutes, or ballutes attached so that the cloud is monitored during a slow descent[10,25]. With this concept, the payload would move with the relative air mass. Also, cloud turbulence and pollution introduced by the platform would be negligible.

Ballutes can be built which descend at 1.3 m/sec for any payload weight of interest in this report. Descent rates less than about

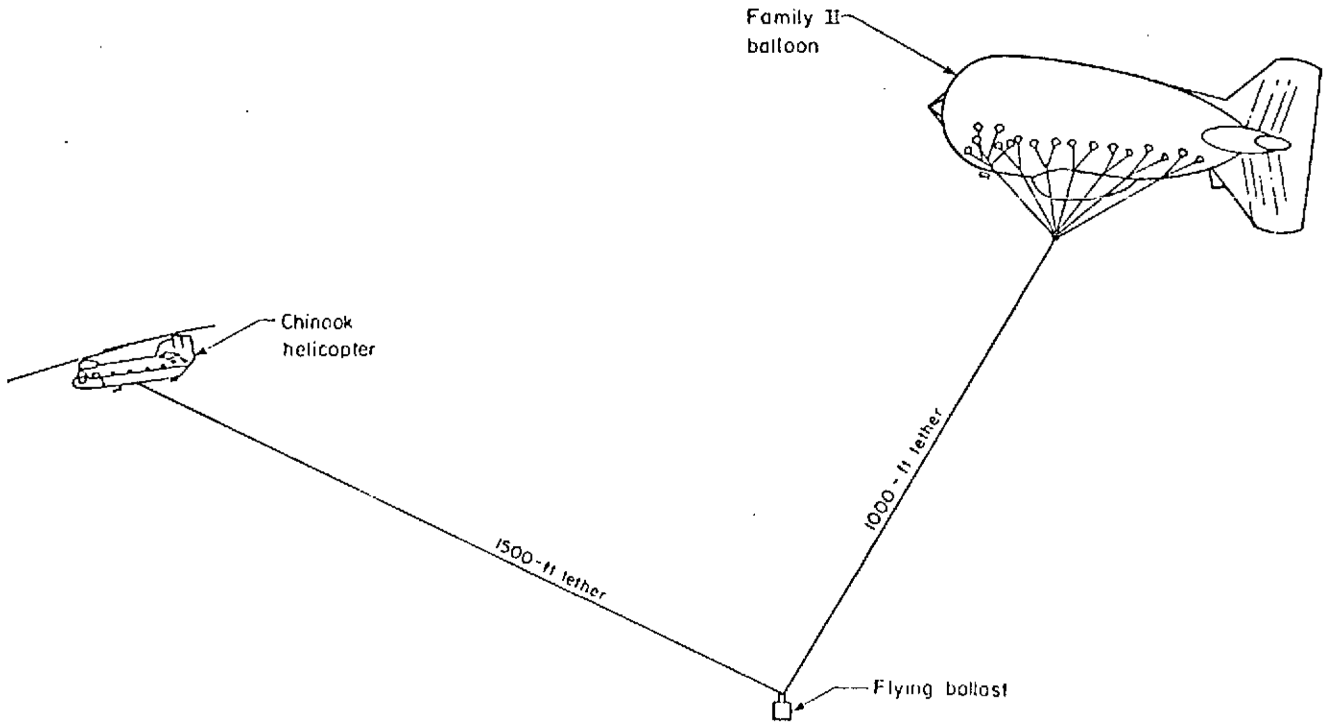

FIGURE 5. A DEMONSTRATED CONFIGURATION FOR TOWING A TETHERED BALLOON

1.1 m/sec cannot be achieved[10]. With slow descent rate, mid-air recovery is possible and has been demonstrated in two classified programs with AC-130 fixed-wing aircraft. The capture success ratio in these programs has been quite high. Helicopters have also demonstrated the capability to capture ballutes in mid-air[10].

In Goodyear Aerospace Corporation's PARD program, a ballute system, which improves the chances of a successful pilot recovery, is being developed. With this system, the air which is captured within the ballute is heated by propane gases. When the captured air becomes warm enough, the pilot remains suspended by the "hot-air balloon" until he is rescued in mid-air, or drifts to friendly territory. The pilot can control his elevation. Such a system might be used to support an instrumentation package, but this system is still in development.

There is the possibility of obtaining data by hard mounting the sensors on the platform and flying the platform through the cloud. A life support system would, of course, be required if a man is onboard the platform. Candidate platforms are sailplanes and light aircraft and small RPV's. The desired requirement of simultaneously sampling at least five points within the cloud would be difficult to achieve. Also, the presence of the platform within the cloud will cause some air turbulence.

It is conjectured that the turbulence caused by the sailplane would have negligible effects upon the experiment; whereas, turbulence caused by light, fixed-wing conventional aircraft may not. Conversely, the air turbulence within the cloud may also effect the platform. In fact, turbulence 2 minutes after launch might be great enough to destroy a sailplane or conventional aircraft. However, some light planes have apparently flown through a cloud formed at the Cape by rocket exhaust, but strong turbulence was not observed.

Sailplanes and conventional fixed-wing aircraft obtain a lift force as a result of their forward velocity. Stall speeds for the Schweitzer 1-34 sailplane are about 75 km/hr, with a sink rate of .9 m/sec. With this minimal forward velocity, the sensor will undergo displacements equivalent to about 10 percent of the width of a 1000-meter cloud, if 60 seconds are required to collect samples for one experiment. Although the aircraft may spiral, within the cloud, sampling with a sensor hard mounted to the platform will only provide an average spatially distributed value of the cloud parameters.

Of all the miniature remotely piloted vehicles, the Mini-Sniffer, being developed by NASA, appears to be the most suitable platform to monitor the cloud. This system, weighing 66 kg with a payload of 11 kg, is specially designed to monitor high altitude (30,500 m) atmospheric pollution.

According to reference 26, a full-scale prototype of the system is presently under construction and is scheduled to fly in May, 1974, at altitudes up to 4600 to 6100 m, which is the operational ceiling of the engine. Flight tests are scheduled to continue through late fall of 1974.

Additional discussions with NASA personnel revealed that at low altitudes, in the neighborhood of 1500 m, a 32 kg payload could be achieved. Wing loading would be about 5 kg/m^2, with a minimum velocity of 56 km/hr, climb rate of about 14 m/sec, and a turn radius of 61 m. Some instrumentation packages are also being specially designed to fit the Mini-Sniffer. The above data are first order estimates and, therefore, subject to some variation. At this time, the use of the Mini-Sniffer to monitor the cloud formed by a missile launch is largely dependent upon financial support(6). It appears to be an excellent candidate.

Summary of Candidate Platforms

The previous discussion evaluated the candidate platforms relative to their ability to perform the required mission. A summary of the evaluation is presented below.

(1) Blimps, Balloons, etc.

Tethered - cannot preposition balloon, few large balloons, so cannot set up network

Towed - Only one method demonstrated, requires continuous tow at large velocities, hence, no advantage

Powered - Only Goodyear has powered blimps. These are expensive, have limited availability, and 1500 meter maximum altitued.

(2) Heavier Than Air

Fixed Wing - Available, but have physical/chemical disturbance of cloud

Rotating Wing - Limited capabilities at 3000 meters, potentially large physical/chemical cloud disturbance

Towed Packages - Short line, slow speed is demonstrated; long line, slow speed is possible, but testing is recommended. Fast speeds and long cables are possible; fast speeds and short cables are unstable. Circling line requires significant development, high pilot skill.

(3) Drop-Through - Package may require mid-air recovery, necessitating skilled operators and special equipment. Otherwise feasible and available.

Payload Position Within the Cloud

Useful test results require that measured data describing the effluence of the cloud must be related to a set of cloud coordinates. Also, real-time knowledge of the payload's position within the cloud is necessary to optimally position the payload during tests.

The payload could be tracked by radar. Candidate systems, which now exist at the Cape and operate in the C-band, include the AN/FPS-16, the AN/FPQ-6 fixed radar and its transportable version, the AN/TPQ-18. These systems are monopulse radars which are primarily designed and suited for missile tracking; and so they are able to beacon (transponder) or skin tract the payload with high accuracy. Positional data is provided in terms of azimuth, elevation and range. Data describing the characteristics of each system are shown in Reference 27. Other candidate radar systems are probably available at the Cape, but information on additional systems was not obtained.

The radar will establish the position of the instrumentation package in an Earth coordinate frame of reference. However, it is necessary to define the position of the instrumentation package within the cloud. This is accomplished by also measuring the cloud in terms of an Earth coordinate frame of reference, and then performing a simple transformation of the data.

Although the cloud cannot be detected by the radar, there are a number of optical trackers which are capable of monitoring the cloud during daylight hours. All of the major systems accurately monitor time, and measure azimuth, and elevation; two optical systems are required to determine range by triangulation. All systems are synchronized.

The Askania KTH-53 cinetheodolite is a metric tracking instrument with a 35-mm double frame camera movement for data recording. At the launch site, three Askanias are mounted on mobile vehicles, while a fourth unit can be mounted in an astrodome-tower configuration.

Mobile Contraves Cinetheodolite 23, which can be located at locations throughout Merritt Island and the Cape, are additional 35-mm film metric instruments capable of accurately tracking the cloud. A closed-circuit television system mounted on the cinetheodolite and collimated with the object allows remote control. In the future, accessory equipment can be procured to provide real-time output of digital angles. Data from two cinetheodolites would establish the xyz coordinates of the cloud.

The Intermediate Focal Length Tracker (IFLOT) is another system with the capability to monitor the cloud. There are ten mobile units available which can mount a 16, 35, or 70-mm camera.

Reference 18 provides a brief description of the three noted photogrpahic systems which could monitor the cloud. In addition, there are over two hundred 16, 35, and 70-mm motion picture cameras in the photo contractor's inventory. A few of these systems, no doubt, have the capability to monitor the cloud's position. Data were not obtained during this study on these additional systems.

Films and thermal instrumentation can document the structural features of the cloud. However, establishing the center of the cloud from film data is a somewhat ambiguous task for a human observer simply because the bounds of the cloud are not well defined. Stereo photogrammetry could be used to produce a stereo image of the cloud, and this may assist the human; however, there is likely to be large variations in his estimate of the cloud center. Another approach is to use a density slicing viewer to establish the centroid of the cloud's density.

The best method of determining the center of the cloud is, of course, dependent upon the mathematical definition of the origin of the cloud, which is used in the mathematical model being verified by these tests.

It is desirable to know the cloud coordinates in real time so that the payload can be optimally positioned. However, the human judgment can probably determine cloud position to sufficient accuracy to permit acceptable data collection.

The previous discussion has shown that a number of sensor systems have the capability to monitor the cloud and payload. If these systems are also used to monitor the missile during initial flight stage, they will not be available to monitor the cloud until the missile is out of the sensor's range. For example, cinetheodolite (optical) systems cover missile flights up to 100,000 ft. Therefore, such systems are in use for about the first two minutes following launch. An additional amount of time is required to unload and reload the film from the camera before they are capable of monitoring the cloud. Radar systems, which are needed to monitor the payload position in the cloud, can track the missile for longer ranges than film; and so the time delay before radar systems can monitor the cloud will likely be even longer. This time delay is likely to prevent monitoring of the cloud as soon as it becomes stable.

Sensor and Platform Capture

Following the successful completion of the cloud monitoring task tests, the platform and payload must safely return to the base, assuming, of course, that the payload is not dispensible. During this phase of the mission, there are no platform velocity requirements and the pilot can maneuver as he wishes. Any platform which has been discussed can meet these trivial requirements. In addition, the stabilization of the towed payloads which was a potential problem during the deployment phase, is not a problem when the platform returns to the base because the pilot can fly at low speed.

If the platform is landing in a configuration where the payload is being towed, then the instrumentation within the payload might be damaged. However, with careful planning, this potential problem can be eliminated by either hauling the payload aboard the platform before landing, or by carefully landing the payload followed by the platform.

Constraints

The operation of aircraft in the vicinity of the Eastern Test Range requires that specific attention be given to the constraints of the Eastern Test Range, Patrick Henry Air Force Base, Federal Aviation Authority, and other authorities who control airspace in the vicinity of the Cape. The requirements of each agency will be discussed separately.

The Eastern Test Range

The launch of a vehicle is a complex procedure, involving the precise timing and integration of electronic machinery to assure a timely, but safe, launch and flight. The cloud sampling procedure cannot interfere with the launch, cannot violate range safety requirements, and cannot offer a hazard to the personnel and equipment at the Cape.

The safety requirements during the Titan launch sequence require aircraft to remain approximately 2 miles to the north or west of the launch pad until 1 minute after launch, as in Figure 6. The area to the south and east of the pad must be vacated. Approximately 1 minute after the launch, as announced by the Senior Range Officer, the barriers become transparent.

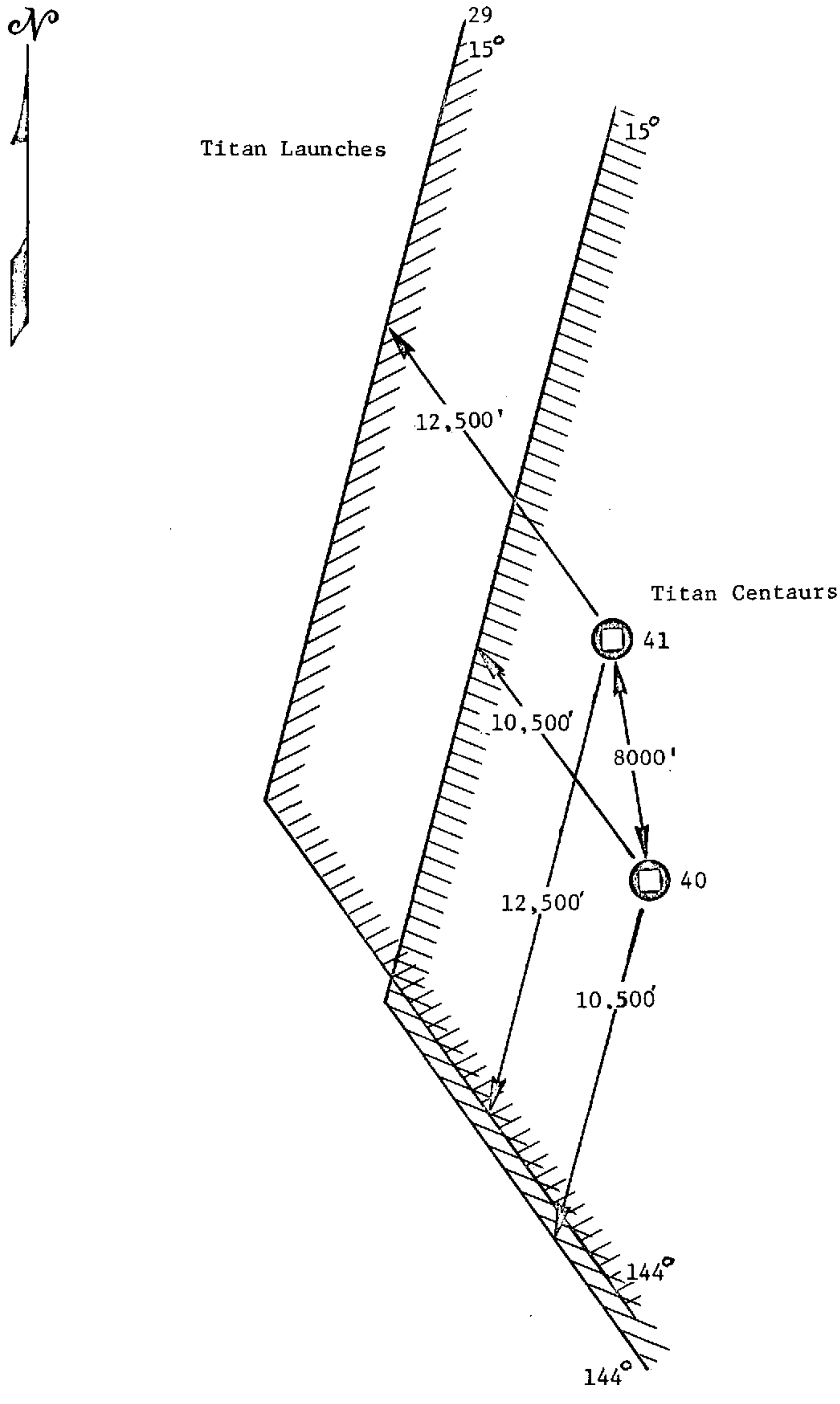

FIGURE 6. STANDOFF BARRIERS FOR AIRCRAFT

Barriers disappear 1 minute after launch.

Prior permission must be granted for aircraft operations over the Cape, defined in Figure 2. This may be granted via a formal request in writing to KSC Range Scheduling, detailing the flight plan and reason. A clearance number will be assigned for the specific flight. During the flight, continual radio contact must be kept with the SRO.

The area surrounding the Vehicle Assembly Building and the Saturn V launch pads is restricted to an altitude of 3000 ft. In the event the cloud were to pass over the area, the mission aircraft would have to clear this defined obstacle.

Although the range requirements are stringent, the pilots at the Cape are familiar with them. One pilot said that they would be glad to brief any new pilot as to the procedures that have to be followed. He also implied that flight operations over the Cape are routine, in spite of the apparent stringency of the rules[28].

Miami Air Traffic Control Center

The mission will probably involve operations into Control Area 1232, under the authority of the FAA, Miami ARTC Center, as defined in Figure 2. Permission must be obtained from this agency prior to entering the restricted airspace, but the permission can be granted via radio. In the interests of mission safety, to prevent interference from other aircraft, it is desirable to submit a written request prior to the launch.

Federal Aviation Authority

Uncommon FAA rules that have a direct bearing on the mission are presented in Appendix B. These rules will be discussed, as needed, in the discussions of selected systems. Suffice it to say that many of them can be broken via a written request to the Administrator of the FAA.

Wildlife Refuge

Operations over the Merrit Island National Wildlife Refuge may be necessary, though unlikely. A written authorization must be requested from the Merrit Island Refuge officials for aircraft operations over the Refuge at less than 305 meters (1000 ft).

Instrumentation

The instrumentation for the primary mission must measure the gaseous species of HCl, CO, and CO_2, within the cloud. The aluminum oxide component of the airborne particulate must also be measured. It is also desirable to monitor the temperature, relative humidity (or gaseous H_2O), and total H_2O content.

Mission Considerations

As the instrumentation will be airborne on a platform which may not be stationary, several special considerations must be considered for the choice of instruments. These include

(1) Weight. As some of the platforms are weight limited, the instrumentation choice may be severely constrained.

(2) Power. The voltage, frequency, and power requirements of the instrumentation must be made compatible with the platform. The effects of power fluctuations should be considered.

(3) Response Time. In as much as the platform may be moving through the cloud (which may be as small as 500 m), the response time of the instrument should be small enough to afford resolution of the cloud cross-section. As a suggested guide, the 90 percent response time of the instrument should be less than the time required to traverse 10 percent of the cloud.

It is conceptually possible to mathematically remove both the lag time and instrument response time effects from the measured profiles. In fact, computer programs already exist for this purpose. However, the numerical differentiation required will exaggerate the noise in the data.

(4) Vibration. The instruments should not be susceptible to the vibration of the platform (or its orientation).

(5) Automation. The instruments which are placed on platforms that cannot also carry a technician must be capable of functioning reliably without intervention.

(6) Altitude. The species to be measured are not at sea level atmospheric pressure.

Atmospheric Reactions

The specification of instrumentation to monitor the concentrations of the desired species in the cloud is complicated by the complicated heterogeneous chemical and physical reactions that may occur within the cloud.

Table 1 presents a list of the primary elements expected in the cloud (except oxygen and nitrogen) and their expected states. In particular, the aluminum oxide, water, and hydrogen chloride are strongly interrelated forming a mixture of gas and aerosol related compounds. The equilibria states of these compounds are highly dependent upon concentrations, relative humidity, and temperature.

Appropriate Instruments

As the act of sampling can alter the states of the compounds present, it is desirable to restate the objective of the mission. The purpose of the sampling is to provide data for calibration of a transport /diffusion model, a model which does not address the problem of either homogeneous or heterogeneous chemistry.

With this purpose in mind, it is desirable to discuss the potential measurement techniques which may be employed. Table 2 presents a list of techniques examined for their utility to this study.

With the exception of spectroscopy, these techniques are all contact sensors, requiring a physical extraction and manipulation of a sample. The techniques are fairly well known, and, thus, are not discussed here in further detail. Appendix A contains, in a matrix form, more specifications of these instruments.

TABLE 1. ELEMENTS PRESENT AND THEIR STATES

Aluminum -	Evidence suggests that the aluminum oxide has a γ crystalline structure--hence, it is hygroscopic and soluble in strong acids. It is expected that Al_2O_3 particles will exist at the core of acid aerosols, hydrated by up to three water molecules. In addition, some aluminum will exist as $AlCl_3$ in solution[3].
Chlorine -	The chlorine in the propellant combines with the hydrogen to produce HCl gas. This gas will react rapidly with H_2O and Al_2O_3 to produce strong acid (5 percent molar) aerosols. Background chlorine will be present from the salt suspended from the Atlantic Ocean (up to .5 ppm[29]).
Hydrogen -	This element combines with both chlorine and oxygen. The water vapor formed will cool and condense into a visible aerosol. The hydrogen attached to chlorine in solution will be ionized.
Carbon Oxides -	Both CO and CO_2 are formed during propellant combustion. Afterburning of much of the CO occurs[2]. A little carbonic acid may form in the aerosol.

TABLE 2. POTENTIAL MEASUREMENT TECHNIQUES

Constituent		What is Measured*	How	Comments
Al_2O_3	S	Total mass	Piezo-crystal	Aqueous aerosol interference
	A	Total dry mass	Filter-gravimetric	Post-flight analysis
	A	Total aluminum	Filter-atomic abs	Post-flight
	A	Total aluminum	Atomic emission	Expensive
	S	Total aluminum	Laser evaporation and spectroscopy	Not yet available
Al_2O_3 Analogues	S	Particle count	Photometry	Nonhomogeneous particles
	S	Light scattering	Integrating Nephalometer	Nonhomogeneous particles
	S	Light absorbtion	Photometry	Nonhomogeneous particles
	S	Light scattering and AA analysis of filter	Integrating Nephalometer and millipore filter	Post-flight analysis
HCl	S	HCl Gas	Colorimetric	Low accuracy
	A	Total HCl	Electrical conductance	$AlCl_3$ interference
	A	Total Cl	Coulimetric	Best Available
	S	Gaseous HCl	NDIR	May have problems with sample cell

* S Measurement on continuous sample.

A Measurement on accumulated (hence time averaged) sample.

TABLE 2. (Continued)

Constituent	What is Measured	How	Comments
HCl (Continued)	S Gaseous HCl	Spectroscopy*	No sample handling problem
	S Gaseous HCl	Chemoluminescent	No sample handling problem
	S Gaseous HCl	Polarography	Not available
	A Total HCl	Wet Chemistry	Post-flight analysis
HCl Analogues	A Total Cl	Electrical conductance, Chlonde specific electrode	NaCl interference
	S Total H^+	Electrochemical	Lightweight
CO, CO_2	S Either Gas	NDIR	
	S Either Gas	Spectroscopy*	H_2O interference
	S CO	Heat of catalytic oxidation	
	S CO	Electrochemical	
	S CO	Chemoluminescence	
	A CO_2	Electrical conductance	Interferences
	S Either Gas	Polarography	Not available
	A Either Gas	Wet chemistry	Post-flight analysis
H_2O	S Gas	Hygroscopic salts	Slow
	S Gas	Organic sensing	Slow

* Spectroscopy here represents the whole field of wavelength specific molecular absorption-emission phenomena.

TABLE 2. (Continued)

Constituent	What is Measured	How	Comments
H_2O (Continued)	S Gas	Spectroscopy*	
	S	Resistance Strip	HCl interference
	S Total H_2O	Heated sample and gas technique	Complex
	A Total H_2O	Cryogenic freezing	Post-flight analysis, not available
	A Total H_2O	Wet Chemistry	Post-flight analysis
Temperature	S T	Thermistor	

* Spectroscopy here represents the whole field of wavelength specific molecular absorption-emission phenomena.

Spectroscopy presents a way of avoiding the physical sample extraction. This is particularly important for measuring HCl, which as a gas adsorbs on nearly all materials, necessitating sample line conditioning[30] and its concomitant problems. A further discussion on spectroscopy is presented in Appendix C. One off-the-shelf instrument was located which has the capabilities required for the mission (but not the accuracy). It also was quite expensive, with an initial price tag of approximately $100,000. Significant computer time is required to process the data from the instrument[31].

The available techniques are reviewed in the context of the purpose of the mission (model calibration) in Table 3 for HCl and Al_2O_3. The other constituents to be measured are more straightforward, except that acid may interfere with humidity measurements and evaporation may interfere with temperature measurements.

Selection of Candidate Systems

In order to select a candidate system the capabilities of the platforms must be compared to the capabilities of the instruments to produce systems which are internally compatible and externally capable of meeting mission goals. However, it is possible to do some screening of the platforms and the instruments individually to eliminate those which either do not meet system requirements, and those whose capabilities are dominated by others.

Table 4 presents a list of the candidate platforms discussed previously.

These discussions showed that several of the candidates are inacceptable for one or more reasons. The blimp has an extremely high rental rate, a limited altitude, a limited payload, and a limited availability. The ground tethered balloons suffer from a lack of mobility. In a stationary mode, multiple balloons could be stationed in a grid downwind. However, there is a scarcity of the only balloon demonstrated to have the altitude/payload requirement, so the grid would be sparse. Towed balloons have been demonstrated, but the balloon and helicopter

TABLE 3. REVIEW OF Al_2O_3, HCl TECHNIQUES IN CONTEXT OF MODEL VALIDATION

Species	Effect on Validation
Total Aluminum	Allows calibration of model Al_2O_3
Total Mass	Significant H_2O interference
Total Dry Mass	Allows calibration, but small interference from NaCl (1ppm)[29]
Total HCl	Allows calibration, but some loss (and interference) from formation of $AlCl_3$
Total Cl	Allows calibration, but small interference (1ppm) from NaCl
Total H^+	Allows calibration, but some loss from formation of $AlCl_3$
Gaseous HCl	Misses HCl in solution

TABLE 4. CANDIDATE PLATFORMS

Vertical Pass

- Balloons
- Parachutes
- Ballutes

Stationary with Respect to Cloud

- Helicopters
- Blimps

Horizontal Pass

- Manned Fixed Wing
- Remote Controlled Fixed Wing
- Helicopters

Combinations

- Towed Balloons

must be constantly in motion. Since this configuration offers no advantage over the simpler configuration of a towed instrumentation package, it is also eliminated from further discussion.

As a result of the elimination of these configurations, three broad classes of platforms remain. These, which are further discussed below, will be paired with instrumentation packages.

Vertical Pass Devices

Ballutes, parachutes, or small balloons could be used to slowly descend the payload through the cloud at rates of 4 or 5 ft/sec. The major disadvantage of this approach is that a number of instrumentation packages would be required; some may never be recovered. However, the slow descent rates of 4 to 5 ft/sec will allow the vertical resolution of the cloud profile.

Horizontal Pass Devices

It is possible to fly through the cloud with a helicopter, fixed wing aircraft, glider, or RPV. The magnitude of cloud distrubance which is acceptable is not calculated here, but data from helicopter down wash tests indicate that man rated helicopters and aircraft with operational engines would likely alter the relative humidity, temperature, and affluence of local areas within the cloud by a few percent. A man-rated system is desirable, but there is an unknown health hazard to the operator.

Of all the RPV's, the Mini-Sniffer remains the primary candidate to support the cloud monitoring task. However, it is limited in payload (70 lb) and volume. Also, the aircraft and instrumentation are currently in development and they may not be available at the desired time and in an acceptable configuration. It may be difficult to properly control the Mini-Sniffer.

Stationary Devices

A helicopter could hover above the clouds and lower the instrumentation package into the cloud via a long cable. The amount of physical and chemical disturbance of the cloud, which would be created by the helicopter, is dependent upon the weight of the helicopter, its hovering time, and the height of the helicopter above the cloud. Cable lengths in excess of 1000 ft are likely. With this long a cable, the payload/cable form a long pendulum, which may force the payload to undergo displacement within the cloud on the order of tens of feet. Also, this suspended load may be unstable if it is rapidly transported to the cloud in this configuration. Helicopter stabilization systems are available.

Based upon existing information, Table 5 illustrates the advantage and disadvantage of each of the primary platform candidates. The system which is recommended depends upon the relative importance of the indicated platform parameters.

TABLE 5. ADVANTAGES AND DISADVANTAGES OF PRIMARY PLATFORM CANDIDATES

Platform System Effective Parameters	One Helicopter Suspended Load	Slow Descent Devices (e.g., parachutes, ballutes)	Mini-Sniffer	Fly through Cloud with Manned Aircraft
Minimal Effect upon Experimental Results		X	X	
High Probability of Being Available	X	X	?	X
Minimal Potential Damage to Equipment/Personnel	X		X	
Low Cost		X	?	

With three broad classes of platforms selected, it becomes possible to pair acceptable instruments to the platforms. The data for this pairing is contained in Appendix A. The instrument combinations for each of the three classes of platforms are described in the following paragraphs.

The first configuration is a slow descent device, such as a parachute or ballute. A relationship between parachute diameter and weight exists for a fixed descent velocity. With ten positions to be monitored over a period of 1 hour, each drop through the cloud should take less than 6 minutes in order to free tracking equipment for subsequent drops. With a cloud thickness of approximately 500 meters, the descent velocity should be no less than 1.4 meters per second. As the cloud grows, the descent velocity decreed by this consideration also grows. On the other hand, parachute descent velocities lower than 2 meters per second are not feasible. At this velocity, a 6 minute drop would allow a vertical scan of 720 meters. A 3 meter per second descent velocity would allow a vertical scan of 1080 meters. These distances are sufficient to define the cloud vertically, particularly in the earlier drops. The minimum required 90 percent response times of the instruments would be (with a 500 meter cloud) 25 seconds and 16 seconds.

The relationship between drag and weight yields a relationship between parachute diameter and weight, specifically that the parachute diameter in meters is approximately 1.8 times the square root of the weight (in kilograms). In order to have a parachute of reasonable size (a diameter of the order of 10 meters), the weight must be small, on the order of 30 kilograms. It is obvious that the power supply for the instrumentation must be self-contained, so the payload weight must include the weight of batteries.

The instrumentation table of Appendix A, with the constraints of weight, power, and speed, demonstrates only one selection of instruments. Specifically, a small paper tape monitor for Al_2O_3, and detector tubes for the remaining gases. Reference 33 has stated that detector tubes connected to pumps and photoelectric readouts for remote detection had been demonstrated. In this mode of operation, the concentration of gases present may be estimated by the chronological history of tube dosage[33].

NOAA for years has had aerosondes fabricated for using in tracking altitude variations in wind, temperature, pressure, and relative humidity. The instrument packages are made by two manufacturers. The packages weigh under 1 kilogram, complete with battery, and have temperature, pressure, and relative humidity sensors, and a sequencing switch for interrogation. A transmitter relays the information to ground stations. The package can be modified to transmit other information[32].

There is a meteorological radar at the Cape equipped to track such transmitters to receive and record data, and to record position information. The position information is accurate in range to about 10 meters, and in any cross-range direction to about 6 meters. The radar is available for 1 hour after a launch.

In operation, the parachute and instrument package would have to be released from a helicopter directly over the cloud. If night operations are pursued, an IR television on board the helicopter would aid in positioning the helicopter.

The cloud location with respect to the ground would be determined by triangulation from ground based cameras. As discussed in Appendix C, IR scanners on the tracking cameras would allow tracking at night and may assist in the cloud resolution.

The package would have to be recovered in order to retrieve the paper tape sampler, which contains the Al_2O_3 signal. This might be done in midair or after impact.

The chief advantages of the system are that it is cheap, reliable, and provides vertical scans of the cloud profile. Its chief disadvantage is that the data accuracy is poor, with an expected error of 25 percent. The system is summarized in Figure 7.

The second and third configurations address the possibility of utilizing a hovering helicopter as a platform, with the instrumentation suspended via a cable into the cloud. In these configurations, the instrumentation would be essentially immobile, and the instrument response time is, therefore, not critical.

The piezo-crystal mass monitor, due to its light weight and low power requirements is the recommended monitor for Al_2O_3. The indicated

FIGURE 7. CONFIGURATION 1

- Vertical Drop on Parachute or Ballute
- $1/2\ \rho A V^2 C D = W \Longrightarrow R \sim 1.8\sqrt{W}$, hence, W small
- Instrumented by
  - (1) VIZ Corp battery, radio, sequencing switch, temperature, humidity, and pressure (~ 1 kg)
  - (2) Multiple Gastech[R] tubes, photoreadout (~ 5 kg)
  - (3) Miniature tape sampler (~ 1 kg)
  - (4) Electronics (~ 1 kg)
- Ground Equipment
  - (1) Meteorological radar
    - (a) skin track
    - (b) information receive and record
  - (2) Tracking cameras (IR optional)
- Air Equipment
  - (1) Helicopter
  - (2) IR television (optional)
- Advantages
  - (1) Inexpensive
  - (2) Reliable
  - (3) Vertical Scans
- Disadvantages
  - (1) Not accurate
  - (2) Recovery of tape sampler desirable

atmospheric mass loading is affected by volatiles, such as water, impacting on and evaporating off the vibrating crystal. However, the monitor would be essentially stationary within the cloud, and the effect of water evaporation should be minor.

The recommended mass monitor also has a slowly rotating impaction plate. The accumulated mass on this plate can be analyzed after the flight for such variables as aluminum content, (dry) particle size distribution, and aluminum chloride content, all as a function of time.

The instrument information of Table A-2 was scanned to produce the most accurate and specific gaseous sensors. These are presented below.

TABLE 6. ACCURATE AND SPECIFIC SENSORS

Species	Method
HCl	Wet Chemistry
	Coulimetry
	Aerosol Formation
CO	Wet Chemistry
	NDIR
CO_2	Wet Chemistry
	NDIR

The wet chemistry technique is common to the three species, and thus substantial savings in weight, cost, and power can be achieved by utilization of an instrument capable of performing the three analyses simultaneously. Such an instrument exists: it has the capability of performing three simultaneous analyses on 12 separate samples. In operation, the instrument bubbles the sample stream through a series of three reagents for an adjustable period of as small as 2 minutes. After another adjustable period during which no sampling occurs, a sequencing value selects another set of reagents and another sample is taken. As many as

12 samples can be taken. The instrument weighs 21 kilograms, and requires 2 amps at 120 VAC.

In the second set, specific instruments are selected for each of the three species of interest. NDIR is the selected instrument choice for CO and CO_2. In the choice between the remaining instruments for HCl, a microcoulimeter was preferred to the aerosol formation as the latter does not have the range to accommodate expected cloud concentrations.

The remaining instrumentation for both packages is similar to that of the first configuration, except that position data must be provided for the platform. Although it is possible to triangulate on the platform with the film records from two tracking cameras, or to locate the platform using the meteorological radar, data reduction and analysis would be simplified by having the position data recorded with the species data.

Potential instrumentation for position include LORAC, VOR, and inertial navigation. LORAC can provide a positional accuracy of about 25 meters. VOR accuracy is closer to 500 meters, or the size of the cloud. Inertial navigation is more expensive than LORAC. Hence, LORAC is the selected instrument for position data. An altimeter will also be required.

The two instrument packages are summarized in Figures 8 and 9 The instrument package of the second configuration weighs 29 kilograms, and consumes approximately 2 amps at 110 VAC. The third configuration, however, weighs 92 kilograms, and consumes approximately 3 amps at 110 VAC. The weight and power of the instrumentation of either configuration allow multiple instrumentation packages to be slung at various points along the cable.

The cable for the instruments must be capable of supporting the total weight of the instruments, its own weight, and the weight of a power cable. The position of the first instrumentation package beneath the helicopter would have to be 300 meters in order to minimize the effect of rotor downwash. Hence, both the support and power cables will have significant weight*. Appendix D contains information on cables which demonstrate

* 300 meters of insulated 14 gauge (15 amps at 110 VAC) dual conductor copper wire weighs approximately 27 kilograms.

FIGURE 8. CONFIGURATION 2

- Multiple Loads Suspended
- Instrumented by
  - (1) Sequential sampler (21 kg)
  - (2) Piezo-crystal mass monitor

    (5 kg)
  - (3) Electronic temperature, humidity (1 kg)
  - (4) Transmitter (2 kg)
- Ground Equipment
  - (1) Tracking cameras (IR option)
- Air Equipment
  - (1) Helicopter
  - (2) IR television
  - (3) Receivers, recording equipment
  - (4) LORAC location equipment
  - (5) Cape time
- Advantages
  - (1) Inexpensive
  - (2) Accurate
  - (3) Vertical locations
- Disadvantages
  - (1) Hazards and cost of jettisoned load
  - (2) Cloud disturbance by rotor downwash
  - (3) Time averaged (~2 minutes) samples

FIGURE 9. CONFIGURATION 3

- Multiple Loads Suspended
- Instrumented by
  - (1) Microcoulometer for HCl (50 kg)
  - (2) Piezo-mass crystal (5 kg)
  - (3) NDIR for CO, CO_2 (34 kg)
  - (4) Electronic temperature, humidity (1 kg)
  - (5) Transmitter (2 kg)
- Ground Equipment
  - (1) Tracking cameras
- Air Equipment
  - (1) Helicopter
  - (2) IR television
  - (3) Receivers, recording equipment
  - (4) LORAC location equipment
  - (5) Cape time
- Advantages
  - (1) Accurate
  - (2) Real-time results
  - (3) Both phases of H_2O (approximate)
  - (4) Vertical Locations
- Disadvantages
  - (1) Hazards, cost of jettisoned load
  - (2) Cloud disturbance by rotor downwash
  - (3) Slow processing by microcoulometer

that the current state of the art of cables is more than sufficient to support five instrument packages (of either type) and a power cable.

In the fourth configuration, the platform is a fixed or rotary wing aircraft moving horizontally through the cloud. The instrumentation package is the same as in the second and third, except that a chemoluminescent device for HCl is necessary to avoid the problem of HCl adsorption during the transient passes of the cloud. This configuration is presented in Figure 10.

System Discussion

In the previous sections, four systems were selected as best candidates to monitor the clouds. These include:

(1) A slow ascent/decent device (such as a parachute) with suspended payload

(2) Helicopter supporting several suspended payloads

(3) An aircraft flying through the cloud with internal payload.

In this section the comparative advantages and disadvantages of each system are discussed, and a unique system recommended.

The systems were selected by fitting together certain compatible features of acceptable components, without regard to overall system feasibility. After these three systems were postulated, it was observed that the systems which involved helicopters with payloads suspended at large distances from the helicopter did not seem technically feasible (flyable). Contact was made with a pilot* who has lifted heavy (2200 kg) weights at the end of 300 meter cables. The content of his comments is expressed below.

> The weight at the end of the cable acts as a huge pendulum with an extremely long period. Its stability can be controlled by a pilot, but the amplitude of the swing is quite large (inferred more than 15 meters).
>
> There was no real problem in towing the load, but minimal speeds are recommended. A safety link should be installed in the cable to protect against ground snags.

---

* Lt. Colonel Crupper, USAF, Eglin Air Force Base.

FIGURE 10. CONFIGURATION 4

- Fixed or Rotary Wing Aircraft
- Instrumented by
  - (1) Geomet Chemoluminescence for HCl (23 kg)
  - (2) Piezo-mass crystal (6.4 kg)
  - (3) NDIR for CO, CO_2 (16 kg each)
  - (4) Electronic temperature, humidity (1 kg)
- Ground Equipment
  - (1) Tracking cameras (IR option)
- Air Equipment
  - (1) Small airplane
  - (2) IR television (optional)
  - (3) Recorder
  - (4) LORAC location equipment
  - (5) Cape time
- Advantages
  - (1) Horizontal traverses at any altitude
  - (2) Relative safety
- Disadvantages
  - (1) In cloud disturbances
  - (2) Response time of instruments compared to aircraft speed may induce errors

> The high altitude hovering of the primary mission represents an extremely difficult task for both man and machine. It would be much better to allow a slow forward velocity. Even at that, the available power of the machine is so taxed that a pilot would be unlikely to fly the mission. With the power required for hover at altitude, too little is available for control.

That discussion may not be sufficient to totally eliminate the helicopter, but its considerations were weighed into the ranking scheme developed below.

Table 7 provides a comparative rating of the three selected system candidates. The ranking is dependent upon nine parameters considered most significant to accomplishing the desired objectives of the mission. The sum of the individual system rating provides a comparative measure of the overall system capabilities. Platform systems which fly through the cloud with internal loads are shown to have the best overall rating. Slow ascent/decent platforms with suspended platforms are the second choice, with helicopters having one or more suspended loads the least desirable of the three systems.

The primary reason that systems which fly through the clouds are rated superior is that six of the nine parameters used in the rating procedure are favorable to highly developed systems. These parameters include system expense, ease of launch and recovery, availability, reliability, and controllability. It is not surprising that conventional aircraft which merely fly through the clouds with an internal payload have a high rating in these categories. Only three parameters are included in the table which deal with optimizing the actual monitoring task. These parameters include cloud disturbance, vertical measure of the clouds profile, and required response time of the instrumentation. In these categories, slow descent/ascent devices and helicoptors achieve a higher rating than "fly through systems". Suspended loads and low speed capability of the platforms makes these systems more optimally designed to monitor the cloud.

Selection of a recommended system is, therefore, dependent upon the decision to accept one of three alternatives, namely:

(1) To perform each test with a high probability of obtaining useful data; and accepting the possibility

TABLE 7. COMPARATIVE RANKING OF THREE MAJOR PLATFORM SYSTEMS[a]

	Slow Decent Device with Suspended Load	One Helicopter with Several Suspended Loads	Fly Through with Internal Payload
Expense	2	3	1
Launch Problems	2	3	1
Recovery Problems	3	2	1
Platform Control	2	3	1
System Availability	2	3	1
Reliable System	2	3	1
Required Instrument Response Time	2	1	3
Cloud Disturbance	1	2	3
Vertical Measure of Cloud	2	1	3
Total	18	21	15

(a) Lowest rank is best.

that the data may not be totally representative of the cloud structure

(2) To accept a lower probability of obtaining all data samples; and increasing the possibility that if data are obtained, it will be representative of the cloud structure

(3) To accept an intermediate probability of obtaining data, which, although representative of the cloud structure, is much less accurate than the other two.

Because of the expense of each test, and the few number of missile flights, there will only be a few opportunities to monitor the clouds and obtain data. In addition, accurate measurements of species concentration is desired for model calibration. The first option is, therefore, preferable, and so a platform which flies through the clouds with internal payload is recommended as the first choice system.

There are several platforms/sensor systems capable of flying through the clouds. These platforms can be classified into three categories: rotary wing aircraft, small, conventional power, fixed wing aircraft, and unconventional fixed wing aircraft such as the mini-sniffer and gliders. It follows from the previous discussion and Table 1 that the recommended system must (1) produce minimal cloud disturbance, (2) fly at speeds slow enough so that accurate measurements can be obtained at a unique point in the clouds, (3) be configured so that engine exhaust is not sensed by the onboard instrumentation.

Recommended System Design

The previous sections described the reasoning used to select, from the myriad combinations available, the platform and instrumentation best suited for the task of sampling several species within the transient cloud which forms during and after a solid fuel launch vehicle launch. This section is devoted to the details and characteristics of the selected systems.

The platform selected is the Helio Courier. It has an altitude restriction of 1544 meters, a minimum speed of 13 m/sec, and in addition to capable of meeting the operational constraints, offers the capability of slow flight coupled with cargo capacity and light weight.

The instrumentation selected for the mission, briefly described in Figure 10, is detailed below in Table 8. In addition to the instrumentation necessary to monitor species concentration, other items must be carried, including equipment for locating the aircraft with respect to the ground, logging the collected data, conversion of 28 VDC power, and life support equipment. These items, in addition to being detailed in Table 8, are described below.

A lightweight system for obtaining data required in aerial surveys has been developed by Metrodate, Incorporated. This instrument, which couples into the standard complement of aircraft instrumentation, produces analog (± 5 VDC) signals containing the directions to two VOR stations, one DME station, compass heading, airspeed, and altitude. An optional probe, which must be mechanically fixed to the aircraft, allows the production of analog signals for temperature (thermistor) and relative humidity (resistance strip). As there will be water droplets in the cloud, and as the aircraft will be moving quite slowly ($\sim$ 20 m/sec), it is recommended that the probe be modified to provide a cup around the thermistor. In this manner, the thermistor will report total temperature (which is nearly exactly static temperature at low speeds) without the cooling effect from evaporation of volatiles.

The VOR and DME capabilities of the instrument are not accurate enough for the purpose of the mission. The exact position of the aircraft could be derived from triangulation of the photographs of the Askinias, but the aircraft may be obscured by the cloud. A tracking radar could provide coverage, but experience in experimental programs has shown that serious problems frequently arise when data recorded at two separate points have to be correlated. In addition, radar availability is questionable.

TABLE 8. SELECTED INSTRUMENTS

Instrument	Measures For	Weight, kg	Volume, m^3	Power	Cost	Maximum Error	Response Time, sec	Comments
Geomet 401	HCl	23	.111	115VAC, 2 amps	$5500	5 pc	1	Dual Channel eliminates interference
Celesco PM 39D	Particulate	6	.013	115VAC, small	$4500	10 pc	1	Battery version
Beckman 865	CO	16	.044	115VAC, 2 amps	$1925	1 pc	0.5	MSA LIRA has been flown(3
	CO_2	16	.044	115VAC, 2 amps	$1925	1 pc	0.5	MSA LIRA has been flown
Metrodata	Temperature	4	.008	115VAC, .1 amp		.5 C	0.5	
	RH						~10	
	Airspeed					1 m/s		
	Altitude					30 m		
	VOR (2)							
	DME (1)							
LORAC Service Corporation	LORAC	30		115VAC, 1 amp				
Metrodata	Logging	4	.017	115VAC, .2 amp				
Leland	Inverting	28	.047	~0		1 pc		

It is highly recommended that position coordinates be recorded with the concentration data, and the recommended source of position coordinates is the Air Force LORAC network. An instrument is recommended which produces two analog (0-10 VDC) signals of the hyperbolic position coordinates.

These coordinates are measurements of phase differences and are not unique. It is, thus, necessary to maintain a record of approximate position in order to locate exact position. As it is possible that this record may be interrupted in flight, the position capabilities of the Metrodata instrument are of potential importance to the mission.

With the instruments described so far, there exists 12 channels of data (plus time) that need to be recorded. Metrodata, Inc., has a companion instrument for logging 18 channels of information, complete with clock, which is lightweight, small, consumes minimal power, and is compatible with the aerial survey instrument. This system is recommended, although there are other data logging devices with similar capabilities.

Some of the instrumentation requires 115 VAC, whereas aircraft standard voltage is 28 VDC. Thus, an inverter is required. Although solid state inverters exist, they have been known to cause difficulties with aerial surveys[35]. A Leland rotary inverter is recommended as it has the requisite capabilities and has been shown to perform reliably in aircraft.

Secondary Objective

Scenario

The secondary objective of this task is to identify a candidate system for in-situ measurements of gaseous and particulate species in the atmosphere over an urban region. System components should be off the shelf and should be capable of providing a vertical profile of the atmosphere from 10,000 ft to the minimum allowable altitude. Species to be measured include CO, CO_2, particulates, NO, NO_x, SO_2, O_x, HC, and CH_4. The data provided by the system will be compared with data from remote sensing instruments. These instruments may monitor the average value of the atmosphere measured over a 1-Km cross sectional area, or they may monitor the average value of the atmosphere over a cross sectional area of a few meters. Sensors monitoring intermediate-sized areas are also possible.

This secondary task is considerably less complicated than the primary mission of monitoring the cloud formed by missile exhaust. A comparison of these two missions reveals why the secondary task is simpler.

(1) There are no requirements to begin or complete the task of monitoring the atmosphere at a specific time. Hence, the secondary mission will require less ground support. More importantly, the absence of a time constraint permits the platform to travel to and from the cloud at speeds which will not cause load instabilities or difficult platform control problems.

(2) Unlike the primary task, exact positioning of the sensors in the horizontal plane is not required when collecting data for verifying sensors which monitor large cross sectional areas. A horizontal velocity component would, in fact, be desirable since an areal average value of concentration could be so obtained.

(3) Because a fixed mass of atmosphere does not require continual monitoring, atmospheric disturbance by the platform is acceptable, provided the experiment is not adversely affected.

(4) In the secondary task, the atmosphere being monitored creates no threat to the crew or equipment. Onboard safety problems are, therefore, less critical.

On the other hand, the secondary task has more stringent safety requirements for personnel and equipment on the ground below the sensors as the platform will operate over urban areas.

The capability of the sensor platforms to perform each phase of the required mission will now be considered.

Sensor Deployment

The Platform

Deployment of the sensor includes its transportation from a ground station to a position above a dėsignated populated area. Required elevation for the platform range from 3000 m to as close to the ground as possible. There are essentially no time constraints in the deployment phase. Candidate platforms for transporting the sensors are listed in Table 4. Each of these systems was a candidate for the primary task of monitoring the cloud and has been discussed previously.

The maximum elevation requirement of 3000 m can be achieved by all platforms except the Goodyear Blimps, which have a maximum altitude capability of 1,500 m. At this altitude, the blimp's ballonet becomes fully inflated and no blimps currently in the U. S. can rise to higher altitudes.

The more difficult restriction is for the platform to position the sensor as close to the ground as possible without danger to personnel and property. The minimum altitude which can be achieved is determined by the following aircraft regulations.

> 91.79 Minimum Safe Altitudes; General
>
> Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:
>
> (a) Anywhere. An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.
>
> (b) Over congested areas. Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 ft above the highest obstacle within a horizontal radius of 2,000 ft of the aircraft.
>
> (c) Over other than congested areas. An altitude of 500 ft above the surface, except over open water or sparsely

populated areas. In that case, the aircraft may not be operated closer than 500 ft to any person, vessel, vehicle, or structure.

(d) Helicopters. Helicopters may be operated at less than the minimums prescribed in paragraph (b) or (c) of this section if the operation is conducted without hazard to persons or property on the surface. In addition, each person operating helicopter shall comply with routes or altitudes specifically prescribed for helicopters by the Administrator.

It is apparent that helicopters are better suited to perform low altitude monitoring of the atmosphere than other platforms since they can fly at altitudes down to 200 ft with approval by the FAA Administrator. Approval is likely to be granted for two-engine helicopters which are capable of flying with only one engine operational. Based upon FAA regulations, it is very unlikely that unusual aircraft configurations will be permitted to fly over populated areas.

If the payload is being towed, other regulations apply.

<u>91.18 Towing: Other Than Under 91.17</u>

(a) No pilot of a civil aircraft may tow anything with that aircraft (other than gliders as noted under 91.17) except in accordance with the terms of a certificate of waiver issued by the Administrator. However, a certificate of waiver is not issued to tow a glider unless the pilot in command of the towing aircraft is qualified under 61.38 of this chapter.

(b) An application for a certificate of waiver under this section is made on a form and in a manner prescribed by the Administrator and must be submitted to the nearest Flight Standards District Office.

The minimal elevation that a towed payload can achieve has not been determined at this time. In all probability, however, payloads on long cables will not be allowed to fly over populated areas because the pilots must have the capability to cut the payload loose if the mission becomes dangerous. The danger to the pilot and aircraft would most likely be caused by the payload swinging uncontrollably beneath the helicopter. Although a load stabilization system would assist in decreasing the oscillation, the mission must still be considered dangerous to personnel and property on the ground. To further complicate the problem, pilots have reported difficulty in judging the position of the payload relative to the ground (e.g., depth perception problems). A major problem would develop is the payload were snagged on a ground object such as a tree.

There are essentially no time constraints during the deployment phase of the mission. All platforms, including towed loads, can consequently be transported to the site at slow speeds, which will result in minimal stability and control problems. These were a major concern in the primary task.

Monitoring the Atmosphere

After the platform is moved to the desired position, it must support the sensor while data is collected. The total data collection period may vary from a few seconds to a few hours. The upper bound velocity of the platform is dependent upon the degradation of sensor resolution, which occurs with increased sensor velocity.

Slow descent/ascent devices (e.g., balloons, parachutes, ballutes, etc.) can only move horizontally with the local wind. Therefore, they are well suited to validate remote sensors which monitor decameter size cross sectional areas of the atmosphere; but are not well suited to obtain a continuous average value of the atmosphere over a large (kilometer size) cross sectional area.

The most severe criticism of slow descent devices when used over populated areas is the danger to ground personnel and property when they hit the ground. In all likelihood, they will probably not be approved by the FAA even though slow-descent devices can be captured in mid-air.

Likewise, slow-ascent devices will probably not be approved when flying over populated areas. However, a scenario worth mentioning is the use of a super pressure balloon with suspended payload. Following release from the ground of aircraft, the sensors would monitor the atmosphere during the ascent phase. After maximum altitude has been reached, the balloon would remain at this altitude and drift away from populated areas. Mid-air capture would follow. Use of either a slow-ascent or descent device, coupled with a meteorological radar, allows a vertical resolution of species concentration and wind.

Fixed-wing aircraft, of course, provide the highest mobility for the instrument package. Both single and multiengine aircraft have been used in urban sampling. Unfortunately, the spacial resolution of the instrument package is adversely affected as the speed of a platform increases, and aircraft represent the fastest class of platforms. Multiengine fixed-wing aircraft require higher speeds than single engines, due to inherent safety considerations.

The helicopter (without a towed load) appears to be the best platform to monitor the atmosphere. It can travel over a large range of velocities. Also, its minimum altitude is less than any other platform. The major criticism of this platform is that the downwash from the helicopter blades and the engine exhaust may interfere with the experimental results. The pollutants formed by the helicopter downwash have been discussed. At low velocities there appears to be no way to avoid this contamination problem other than to intake air through a tube which is outside the radius of the rotor. This long air intake would probably be unacceptable because of its induced lag on the experimental results[a].

When the helicopters such as the Bell travel at about 40 knots, the downwash and engine exhaust are blown aft of the lower portion of the cargo doors. This condition permits air samples to be obtained without engine or downwash effects[34].

(a) A tube outside of the rotor radius would be 10-15 meters long, and cause a time lag of several seconds, thus affecting the locational precision of the sample. In addition, wall effects of the tube can be expected to interfere with the sample.

Sensor and Platform Capture

After the successful completion of the cloud monitoring task, the platform and payload must safely return to the base; assuming , of course, that the payload is not dispensible. This requirement is trivial for any candidate platform, assuming the payload is mounted internally to the platform. Even if the payload is mounted externally, the pilot is free to control the platform in any way desirable so that stability of the platform is achieved. The only difficulty with external loads is that some problems may develop when landing.

Platform Summary

All platforms except blimps have the capability to transport the payload to a position 3000 m above a populated area. However, the FAA will probably not allow gliders, RPVs, tethered balloons, or platforms with suspended payloads to fly over populated areas because of potential danger to personnel and structures on the ground.

Fixed wing powered aircraft cannot fly at speeds below 40 knots and so they are marginal candidates to measure the effluence of the atmosphere. Some gliders and RPVs can fly at speeds suitable to obtaining an average value of the effluence over a large kilometer size cross sectional area. However, they cannot measure small cross sectional areas of the atmosphere unless instruments with response times on the order of seconds are used. The accuracy of these instruments is poor.

Helicopters are the best candidates to perform the required mission. They can fly at all speeds from zero to 40 knots, except at very high altitudes. Over populated areas they can fly 1000 ft lower than any other platform, assuming approval for the flight plan by the FAA Administrator. When flying at speeds greater than 40 mph, the downwash adn exhaust from the engine is blown past the entrance to the door. Monitoring the atmosphere at this high velocity will permit sampling without comtamination from the helicopters[34].

Instrumentation

The instrumentation for the secondary mission can be discussed somewhat independently of the platform. A general list of pollutant monitors and their characteristics is included in Appendix A.

A list of the constituents to be monitored and their maximum ambient concentrations are presented in Table 9. Comparison of this chart to the instrument characteristics chart yields a list of compatible instrumentation, Table 10. These techniques are available in off-the-shelf instrumentation to measure the pollutants in their ambient concentration ranges.

The previous discussion on platforms demonstrated that the platform would be moving with a forward velocity of at least 20 meters/second. As the instrumentation will provide ground truth for remote sensors, it must also provide sufficient resolution to characterize the optical sample of the remote sensor. At least one of the remote sensors to be compared will be located in a satellite, with sensor resolution of 1 Km. In an urban area where 1-Km averaged concentrations do not change too rapidly, a 90 percent response of the contact sensors might be sufficient. At 20 meters per second, this establishes a minimum response time of 50 seconds, if a linear survey is to be conducted. Of course, a survey could be conducted over a region in a spiral or figure "8" pattern to allow the instruments sufficient time to respond, but the areal size of survey to be conducted would also be decreased.

With a 50-second response time, several large categories of instrumentation are eliminated. These eliminated include the coulimetric, colorimetric, iodometric, and derivative spectroscopy instruments. With these eliminated, comparisons between remaining instruments are more easily accomplished, as in Table 11.

Some of the instrumentation of Table 11 is clearly dominant. For example, the electrical conductance method for SO_2 is clearly superceded by either the potentiometric or aerosol method. The potentiometric is unique for NO, and as a bimodular instrument is available for two channels, the choice of NO_2 instrumentation is swayed also to potentiometric. NDIR

TABLE 9. CONSTITUENTS TO BE MEASURED

Constituent	Minimum Expected Concentration, ($\mu g/m^3$)	Maximum Expected Concentration, ($\mu g/m^3$)	Averaging time, hr
CO	~0	63,000	1.
CO_2	668,000*	982,000*	
Particulate	30*	10,000	24.
NO	0	2,825	.083
NO_x	0	5,500	.083
Ozone (oxidants)	80	1,315	1.
Nonmethand HC (Carbon Equivalent)	0	1,340	1.
SO_2	0	10,000	24.
Water Vapor	400,000*	8,000,000*	
Temperature		-35 ⟶ 50 C	

* Estimate.

TABLE 10. CONCENTRATION COMPATIBLE INSTRUMENTS

Constituent	Compatible Instruments
SO_2	Electrical conductivity
	Potentiometric
	Iodometric
	Colorimetric
	D^2
	Aerosol formation
CO_2	NDIR
CO	NDIR
	Heat of reaction
NO	Potentiometric
	Coulometric
	Colorimetric
	D^2
NO_X ($NO + NO_2$)	Potentiometric
	Coulometric (NO, NO_2 separately)
	Microcoulometric (NO_2 only)
	Coloumetric
	Aerosol formation (NO_2)
Nonmethane hydrocarbons	Dual flame FID
	IR absorption (hexane bands)
	Combustible gas
Ozone	Iodometric
	Microcoulometric
	Colorimetric
	Chemoluminescence
	D^2
Water vapor	Hygrometer
	IR
	Resistance strip
Particulate	Nephalometer
	Photometry
	Piezo crystal

TABLE 11. CONCENTRATION AND RESPONSE TIME FOR COMPATIBLE INSTRUMENTS

Constituent	Instrument	Weight	Power	Response Time	Ranges, $\mu g/m^3$
SO_2	Electrical cond.	8	110 v	20	0-290, 1430, 2900, 14300
SO_2	Potentiometric	5	Battery	5-30	0-570, 150000
SO_2	Aerosol	8	Battery	10	0-2900
CO_2	NDIR	29	115 v, 2 amp	0.5 + flush	0-1 x 10^6
CO	NDIR	29	115 v, 2 amp	0.5 + flush	0-63000
	Heat of reaction	< 45	115 v	30	0-630000
NO	Potentiometric	5	Battery	5-30	0-270, 67000
NO_x (NO_2 + NO)	Potentiometric	5	Battery	5-30	0-400, 100000
	Microcoulomb (NO_2 only)	5	115 v, 5 amp	30	0-62000
	Aerosol	8	Battery	10	0-21000
THC, Methane	DFID	27	110 V, 10 amp	15	0-19200, 77000
	NDIR (Hexane)	29	115 v, 2 amp	15	0-770000
	Combustible gas	4	Battery	10	0-~40 x 10^6
Ozone	Microcoulomb	5	115 v, 1 amp	30	0-2100
	Chemoluminescence	16	110 v, 2 amp	1	0-1050, 2100, 10500, 21000
Water vapor	Al_2O_3	<1		30	0-99 percent
	Resistance	<1	Battery	30	0-99 percent
Temperature	Thermistor	<1	Battery	1	Ambient
Particulate	Nephelometer	25	110 v, 1 amp	6	0-3800
	Photometry	16	110 v, 5 amp	Small	.01-10000
	Piezo Crystal	6	Battery	Small	1-200, 2000

is the clear choice for both CO and CO_2, and a vibrating crystal is the clear choice for particulates. Temperature is most readily measured via a thermistor.

In the remaining choices, the following considerations were made:

SO_2--The potentiometric unit is slightly lighter and faster (5 kg versus 8 kg, and 5 seconds versus 20). Both units claim the same accuracy (± 2 percent full scale). The signal of potentiometric unit, due to its design, depends only slightly on flow rate, while the signal of the aerosol unit is highly dependent upon flow. The aerosol technology is older, more established, and less expensive. The aerosol unit is operable on batteries. The potentiometric unit requires a very high amplification of its signal (on the order of nanovolts), which in turn requires electronics which are marginally stable, sensitive to noise and power supply.

In the absence of operational experience with the potentiometric unit, the instrument choice is the aerosol unit. However, the potentiometric technique is very promising.

HC--The choice here is between a power hungry dual flame ionization device, an NDIR instrument which yields total adsorption in hexane absorption bands (which is not total hydrocarbon), and a modified combustible gas monitor which yields Lower Explosive Limit (L.E.L.)--both with and without methane. The latter approach is being used successfully in aircraft monitoring, but the accuracy of the technique is unknown. The first method utilizes 1000 watts of power and also requires a hydrogen supply. The second method does not provide for disaggregation of the absorbed species. The selected system, not directly tabulated in the tables, is to utilize a single flame ionization detector for total hydrocarbons, and a NDIR unit for methane. The total instrument weight would be 44 kg, the response time would be approximately 1 second, and the power requirement about 400 watts. This system is superior to the others in everything but weight, and allows the measurement of methane and nonmethane hydrocarbons while consuming less power than the dual flame ionization detector.

Ozone--Although a microcoulometer requires less power (115w versus 230w), the chemoluminescent response time (1 second) is more consistent with the other instrumentation. The microcoulometer is less specific than the chemoluminescent unit, as it measures the result of a chemical reaction which reduces iodine. Hence, gases such as SO_2 may interfere in the results. As the chemoluminescent unit dominates in all categories except weight, it is the recommended unit.

Water Vapor--Discussion deferred to later section on auxiliary instrumentation.

Ancilliary Instrumentation

Other instrumentation is required to support a mission of urban air sampling. Position and altitude are the minimum acceptable data. Airspeed is also desirable.

Major urban areas contain one or more VOR/DME stations which broadcast signals on preset frequencies. These signals can be used to triangulate the position of the platform. As an alternative, a radar system could track and record the position of the platform.

A system was found which measures these ancilliary data with a reasonable degree of accuracy, as below.

Variable	Maximum Error
Airspeed	1 m/s
Altitude	30 m
Temperature (with probe)	0.5 C
Humidity (with probe)	8 percent
VOR (2)	±1 deg
DME	3 percent

If the urban stations are 20 Km from the platform, the maximum locational error is 400 meters, an error which seems acceptable. The weight of the package is 4 kg, and the power required is 10 watts at 115 VAC. The system requires coupling to navigational receivers, but these are minimum instrumentation for any aircraft. This system, being lightweight, accurate, and consuming minimal power, is therefore highly recommended.

Data Logging

Several types of recording are available for data logging. These include magnetic tape, paper tape, strip chart. Based upon experience with data systems, the computer compatible magnetic or paper tapes are far superior to strip charts. Furthermore, a magnetic tape unit can be lighter, more reliable, and faster than paper tape.

With the ancilliary data, some 17 channels of information have to be logged. The lightest data logger/recorder found weighs 8 kg, operates from 12 VDC, is compatible with the ancilliary data, contains a clock, and records 18 channels plus time. This system is also recommended.

Inverters

Some of the instrumentation requires 110 VAC, which is not available on aircraft. Recent experience in aircraft sampling has shown rotary inverters to be more reliable than solid state,[32] and thus a rotary inverter is recommended.

Recommended Instrumentation

In summary, the recommended instrumentation and the associated characteristics are

Equipment	For	Weight	Power
Metrodata Logger	Data record	8 kg	12 VDC, 2.4 amps
Metrodata Navigation System	Ancilliary Data	4 kg	110 VAC, 0.1 amp
MSA Billionaire	SO_2	8 kg	Battery
Beckman NDIR	CO	29 kg	110 VAC, 2 amps
Beckman NDIR	CO_2	29 kg	110 VAC, 2 amps
Beckman NDIR	CO_4	29 kg	110 VAC, 2 amps
Environmetrics Farister	NO	5 kg	Battery
Environmetrics Farister	NO_X	5 kg	Battery
MSA FID	HC	13 kg	115 VAC, 2 amps
McMillan Chemoluminescent	Ozone	16 kg	115 VAC, 2 amps

Equipment	For	Weight	Power
Celesco Piezo-Crystal	Particulate	6 kg	Battery
Leland Rotary Inverter (2)	115 V	57 kg	115 VAC, 12.1 amps
TOTAL		209 kg	12 VDC, 2.4 amps Numerous batteries or DV power taps

Platform Selection

Based upon the discussions of the platform section, either a helicopter or a fixed-wing aircraft are the only acceptable platforms for the secondary mission. The instrument selection demonstrates a typical 90 percent response of 10 seconds, and with this speed, either a slow aircraft (30 m/sec) or a helicopter (20 m/sec) provide acceptable spatial resolution (200 meters for 90 percent response).

The choice of platform depends upon the need for data in the first 1000 feet of altitude, as provided by a helicopter, compared to the excess cost of helicopter operation, perhaps 10 times[33] the cost of a fixed-wing craft. This cost difference, however, is ameliorated by the fact that sheet metal modifications are required of the fixed-wing aircraft (to accommodate probes), whereas the instrumentation can be more simply accommodated in a helicopter (as the probes can be simply extended out a side hatch).

Which ever aircraft is selected, it should have the capability to lift two men and 209 kg of instrumentation, and to deliver 1,420 watts of power. Some aircraft which fit these goals include

NASA LRC	Bell 204
NASA LRC	Sikorsky SG2
	Bell 212
	Bell 209
NASA/Wallops	Beechcraft Queen Air 70
	Mooney Chapperral
	Cessna U-3
	Cessna 0-2

If data in the first 1000 feet of altitude need to be obtained, then the choice of platform is restricted to a twin engine helicopter, such as the Bell 209 or Bell 212. If these data are not important, then the recommendation is either a single engine plane such as the Mooney (to allow lower speeds than multi-engines) or the NASA LRC Bell helicopter, which offers low speeds and operating costs nearly as low as a leased fixed wing aircraft.

CONCLUSIONS

After a review of potential airborne systems for in-situ monitoring of launch vehicle exhaust, it was concluded that the objectives would be best met with a system consisting of a Helio-Courier aircraft, Celesco and Geomet instruments for mass and HCl, respectively, and utilization of the LORAC network for aircraft location. Other required instruments were also specified.

Ground support requires either radar or IR imagery. IR imagery, in conjunction with spectral filters, may provide supplementary information.

The secondary mission has a more familiar set of instrumentation, chosen to provide ambient range responses within a 200 meter (90 percent) resolution. Locational information can be provided by the existing network of VOR/DME stations. A Helio-Courier is again recommended, if cost is important. However, if data below 300 meters in urban areas are required, a two-engine helicopter is recommended.

REFERENCES

1. Verbal Communication, NASA/LRC Personnel.

2. Goshgarian, B. B., "Solid Propellant Combustion Gas Analysis Using a Micromotor Technique", Report AFRPL-TR-69-53, Air Force Rocket Propulsion Laboratory, Edwards, California, March, 1969.

3. Rhein, R. A., "Some Environmental Considerations Relating the Interaction of the Solid Rocket Motor Exhaust with the Atmosphere: Predicted Chemical Composition of Exhaust Species and Predicted Conditions for the Formation of HCl Aerosol", JPL TM33-659, December, 1973.

4. Advertising Data supplied by Schweizer Aircraft Co., Elmira, New York.

5. Informal estimate obtained during a private communication with personnel at Schweizer Aircraft (March 1974).

6. Discussion with Mr. Robert Reed on April 1974, NASA Flight Research Center, Edwards AFB, California.

7. Informal estimate obtained during a private communication with personnel at Goodyear Aerospace Corp., Akron, Ohio (April 1974).

8. Information obtained during a private communication with personnel at Sikorsky Helicopter Co. (March 1974).

9. Discussions with Mr. Richard Olilla, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio (March 1974).

10. Information obtained during a private communication with personnel at Goodyear Aerospace Corp (March 1974).

11. Asseo, S. J. and Erickson, J. C., Jr., "The Control Requirements for the Stabilization of Externally Slung Loads in Heavy Lift Helicopters", CAL No. AK-5069-J-1, Cornell Aeronautical Laboratory, Buffalo, New York (December 1971).

12. Etkin, B. and Mackworth, J. C., "Aerodynamic Instability of Nonlifting Bodies Towed Beneath an Aircraft", UTIA TN 65, Institute of Aerophysics, University of Toronto, Toronto, Canada (1963).

13. Shanks, R. E., "Experimental Investigation of the Dynamic Stability of a Towed Parawing Glider", TND-1614, NASA (1963).

14. Shanks, R. E., "Experimental Investigation of the Dynamic Stability of a Towed Parawing Glider Air Cargo Delivery System", TND-2292, NASA (1964).

REFERENCES (Cont)

15. Shanks, R. E., "Investigation of the Dynamic Stability and Controllability of a Towed Model of a Modified Half-Cone Reentry Vehicle", TND-2517, NASA (1965).

16. Poli, C. and Cromack, D., "Dynamics of Slung Bodies Using a Single-Point Suspension System", Journal of Aircraft, Vol. 12, No. 2, pp 80-86 (February 1973).

17. Szustak, L. S. and Jenny, D. S., "Control of Large-Cone Helicopters", Journal of American Helicopter Society, Vol. 16, No. 2, pp 11-22 (July 1971).

18. Szustak, Leonard S., and Jenny, D. S., "Control of Large Crane Helicopters", Journal of the American Helicopter Society (July 1971).

19. Cannon, T. C. and Genin, J., "Three-Dimensional Dynamical Behavior of a Flexible Towed Cable", Aeronatuical Quarterly (August 1972).

20. Cannon, T. C. and Genin, J., "Dynamical Behavior of a Materially Damped Flexible Towed Cable", Aeronautical Quarterly (May 1972).

21. Movie film supplied by Sikorsky Helicopter Corporation.

22. "Standard Aircraft Characteristics AF Guide Nr. 2", Vol. No. 2, Brown Book, 5th Edition, Wright Air Development Center, U.S.Air Force.

23. Plank, V. G. and Spatola, A. A., "Cloud Modification by Helicopter Wakes", Journal of Applied Meteorology, Vol. 8 (August 1969).

24. Dickson, D. H. and Oden, J. R., "Fog Dissipation Techniques for Emergency Use", U.S. Army Electronics Command, Research and Development Technical Report ECOM-5420 (January 1972).

25. Payne, J. C., Young, E. Major., USAF, and Rice, Catherine, "Launching of Small Inflated Balloons from Cargo Aircraft", Air Force Cambridge Research Laboratories, AFCRL-TR-73-0276 (April 20, 1973).

26. "Stratospheric Survey Aircraft Developed", Aviation Week and Space Technology (April 15, 1974).

27. AFETR Instrumentation Handbook, Directorate of Range Engineering, Instrumentation Division, Air Force Eastern Test Range, Air Force Systems Command, Patrick Air Force Base, Florida, ETR-TR-71-5 (September 1971).

28. Verbal communication with Lindy Mason, KSFC pilot.

REFERENCES (Cont)

29. Israel, H. F., Israel, G. W., Trace Elements in the Atmosphere, Ann Arbor Science, Ann Arbor, Michigan, 1973.

30. Reyes, R. J., Vasil, and Miller, "Field Testing of HCl Analyzer for Monitoring Solid Rocket Motor Exhaust, 2nd Joint Conference on Sensing of Environmental Pollutants, Washington, D.C., December, 1973.

31. Verbal communication with Block Engineering Company.

32. Verbal communication with Maurice Friedman of VIZ Corporation.

33. Personal communication with Richard Bronner of National Mine Service Company.

34. Personal communication with E. Perkins of LAARP.

35. Adams, D. F., and Koppe, R. K., "Instrumenting Light Aircraft for Air Pollution Research, Journal of Air Pollution Control Association, Vol 19, No. 6, June, 1969.

36. Parts, Leo, et. al., "An Assessment of Instrumentation and Monitoring Needs for Significant Air Pollutants Emitted by Air Force Operations and Recommendations for Future Research on Analysis of Air Pollutants, Monsanto Research Corp., Report ARL 74-0015 (January 1974).

37. McGregor, W. K. et al., "Concentration of OH and NO in YJ93-GE-3 Engine Exhausts Measured in situ by Narrow-Line UV Absorption", Proceedings of the 2nd Conference, Climatic Impact Assessment Program, 14-17 November 1972, A. J. Broderick, Editor, Report No. DOT-TSC-OST-73-4, p 214 (April 1973).

38. Neely, J., and Davidson, D. L., "Emission Level of the YJ93-GE-3 Engine, An SST-Like Engine", Proceedings of the Second Conference on the Climatic Impact Assessment Program, 14-17 November 1972, A. J. Broderick, Editor, Report No. DOT-TSC-OST-73-4, p 180 (April 1973).

39. Hinkley, E. D., "Development and Application of Tunable Diode Lasers to the Detection and Quantitative Evaluation of Pollutant Gases", Final Technical Report on Contract F19628-70-V-0230, 30 September 1971; ibid., "Development of In Situ Prototype Diode Laser System to Monitor SO_2 Across Stack", Final Report to EPA on Contract 68-02-0569 (May 1973).

REFERENCES (Cont)

40. Anon., "Pollutant Measurement Needs Elicit Advanced Instrumentation and Computer Techniques", Anal. Chem., 45, 407A (1973).

41. Ludwig, C. B., et al., "Study of Air Pollutant Detection by Remote Sensors", Report NASA CR-1380 under Contract No. NAS 12-630 (July 1969).

42. Duncan, L. G., et al., "An Airborne Remote Sensing System for Urban Air Quality", MITRE Corp., Report MTR-6601 (February 1974).

43. Micale, Edward C., and Poli, Corrado, "Dynamics of Slung Bodies Utilizing a Rotating Wheel for Stability", Journal of Aircraft, Vol 10, No 12, p 760-763 (December 1973).

APPENDIX A

SUBSYSTEM MATRICES

TABLE A-1. AIRCRAFT CHARACTERISTICS

Platform	Gross Weight, Kilograms	Payload-Altitude, Kilograms	Maximum Speed, Meters/Second	Minimum Speed, Meters/Second	Mission Time	Cloud Effect on Platform	Climb Rate, Meters/Minute	Number of Engines	Cargo Volume	Access Electrical Power	Notes
Rotating Wing											
Bell 47G-5A	1,338	480 @ SL	47	0	<2.0 hrs.		302	1	3 seat	Power Kit Available	Cargo hod 455 kg
Sikorsky S-58T	5,896	2,540 @ SL	60	0	2.0 hrs.	None		2 Turbine	Fuselage 14.4 m	Available	Hover Ceiling= 1,433 m
HH-19B	2,400	360 @ 1,500 m	52	0	<2.0 hrs.		335	1			
CH-47A	15,000	3,600 @ 1,500 m, 600 @ 3,000 m	50-30	0	2.0 hrs.	None	455-230	2	Fuselage 15.5 m		8 Ton Cargo Hod
Fixed Wing, Manned, Powered											
Cessna 172	1,043	461 @ SL	62	25	2.5 hrs.	None	196	1-150 hp	2 m^3	60 A, 12 V	
Cessna 402	2,857	1,000 @ SL	100	35	8 hrs.	None	491	2-300 hp	8.5 m^3	50 A, 24 V	
Beechcraft Air Queen 70	3,992	1,273 @ SL	106	35			388	2	10.0 m^3		
Heliocurior	1,544	600 @ SL	55	13	4 hrs.		350	1	3.0 m^3	Unlikely	6 Seat Plane
Fixed-Wing RPV											
Mini-Sniffer	85	30 @ 1,500 m	233	50	2 hrs.	Possible Turbulence	45	1		Unlikely	
Fixed-Wing Gliders											
Schweizer 1-34	380	120 @ SL	50	18 @ 1 m/sec sink	Unlimited	Possible Turbulence	Thermal Dependent	0	1 seat	None	
Schweizer 2-32	600	230 @ SL	65	18 @ 1 m/sec sink	Unlimited	Possible Turbulence	Thermal Dependent	0	2 seat	None	
Slow Descent Devices											
Parachutes/Balloons with 5 kg payload	7	5	Free Fall	2	1 min in 120 min cloud	Possible Turbulence	2 m/sec	0	Unlimited	None	Demonstrated mid-a capture
Parachutes/Balloons with 50 kg payload	70	50	Free Fall	2	1 min in 120 min cloud	None	2 m/sec	0	Unlimited	None	Demonstrated mid-a capture

TABLE A-1. Continued

Platform	Gross Weight, Kilograms	Payload-Altitude, Kilograms	Maximum Speed, Meters/Second	Minimum Speed, Meters/Second	Mission Time	Cloud Effect on Platform	Climb Rate, Meters/Second	Number of Engines	Cargo Volume	Access Electrical Power	Notes
Lighter-Than-Air Platforms											
Blimps	4,090	325 @ 1,500 m	22	0	Unlimited	None	13 m/min to 400 m	2	Unlimited	760 lights	Goodyear's Blimp
ARPA Family II Tethered Balloon	2,850	610 @ 3,000 m	Velocity of Anchor	0	Function of cloud drift	None	60-150	0	Unlimited	1.5-3.0 kw	
Natural-Shaped Balloon (helium or hot air)	180	610 @ 3,000 m	Local Wind Velocity	Local Wind Velocity	Drifts With Cloud	Possible Turbulence for Small Systems	150	0	Unlimited	None Available	

TABLE A-2 INSTRUMENTATION FOR PRIMARY MISSION

Species	Method	Approximate Weight, kg	90 Percent Response Time, sec	Power Required	Vibration	Automatic Operation	Comments
CO	NDIR	17	3	90-130V, .6 amp	no	yes	
CO	Detector Tube	0	N/A	small	no	yes	Low accuracy
CO	Heat of Cat. Oxidation	<45	30	115V	no	yes	
CO	Chemoluminescence	16	10	115V, 3 amps	no	yes	
CO	Wet Chemistry	7	N/A	110V, 1 amp			
CO_2	NDIR	17	3	90-130V, .6 amp	no	yes	
CO_2	Detector Tube	0	N/A	small	no	yes	Low accuracy
CO_2	Electrical Conductance	30	20	small	no	yes	
CO_2	Wet Chemistry	7	N/A	110V, 1 amp	no	yes	
H_2O	Hygroscopic Salts	<1	very slow	small	no	yes	
H_2O	Detector Tube	0	N/A	small	no	yes	Low accuracy
H_2O	Organic Indicators	<1	very slow	small	no	yes	
H_2O	Resistance Strip	<1	10	small	no	yes	Acid interference
H_2O	Wet Chemistry	7	N/A	110V, 1 amp			
H_2O	NDIR	17	3	90-130V, .6 amp	no	yes	
Temperature	Thermistor	<1	<1	small	no	yes	Must avoid evaporative cooling
Al_2O_3	Piezo-Crystal	5	small	110V	see comment	yes	In theory, vibration could remove collected aerosol, causing error in data reduction
Al_2O_3	Paper Tape	29	N/A	115V, 2.6 amp	no	yes	Includes Recorder
Al_2O_3	Paper Tape	1	N/A	Batteries	no	yes	

TABLE A-2 (Continued)

Species	Method	Approximate Weight, kg	90 Percent Response Time, sec	Power Required	Vibration	Automatic Operation	Comments
Al_2O_3	Atomic Emission	64	small	115V, 15 amps	slight	no	Accurate, power hungry
Al_2O_3	Particle Count	3	4	9 "C" batteries	no	yes	
Al_2O_3	Nephalometer	25	6	110V, 1 amp	no	yes	
Al_2O_3	Photometry	16		115V, 5 amps	no	yes	Logarithmetic Scale
HCl	Detector Tube	0	N/A	small	no	yes	Pump, remote readout also required, low accuracy
HCl	Electrical Conductance	30	20	110V	no	yes	
HCl	Coulimetric	~50	6 minutes /determination	110V	no	no	Accurate determination of Cl
HCl	Chemoluminescent	23	small		no	yes	Possible interferences, no adsorption problem
HCl	Wet Chemistry	7	N/A	110V, 1 amp	no	yes	Accurate determination of accumulated HCl
HCl	Chlonde Specific Electrical Conductance	30	20	110V	no	yes	
HCl	Electrochemical	4	50	115V, 0.1 amp	no	yes	

TABLE A-3. ADDITIONAL INSTRUMENTATION REQUIRED FOR SECONDARY OBJECTIVE

Type	Constituent	Weight, kg	Power	Response Time, sec	Range, ppm	Comments
Electrical Conductivity	SO_2/NH_3	7	115V	~60	0-5, 0-10	
	H_2S/NH_3	7	115V	~60	0-5,1-10	
	SO_2	27	110V, 1 amp	20	0-1	Integral recorder
	Ionizing Gases		115V	20	0-1	
Potentiometric	SO_2	5	115V, .05 amp or battery	5-30	0-.2 up to 0-50	
	NO	5	115V, .05 amp or battery	5-30	0-.2 up to 0-50	
	NO_2	5	115V, .05 amp or battery	5-30	0-.2 up to 0-50	
	NO_x	5	115V, .05 amp or battery	5-30	0-.2 up to 0-50	Integral recorder
Iodometric	Ozone	32	110V, 4 amps	120	0-1	
	SO_2 and Ozone	70	115V	210	0-.1, 0-5	
Coulometric	SO_2	34	115V, 2 amps	240	0-.5, 0-1, 0-2, 0-4	
	Total Oxidants	34	115V, 2 amps	600	0-.2, 0-.5, 0-1	
	NO	34	115V, 2 amps	600	0-.2, 0-.5, 0-1	
	NO_2	34	115V, 2 amps	600	0-.2, 0-.5, 0-1	
Microcoulometric	Ozone	5	115V, .1 amp	30	0-1	
	NO_2	5	115V, .5 amp	30	0-30	
Heat of Reaction	CO	<45	115V	30	0-500	

TABLE A-3. (Continued)

Type	Constituent	Weight, kg	Power	Response Time, sec	Range, ppm	Comments
ombustible Gases	HC	2	Battery	10		Calibrated in terms of lower explosive limit
	Nonmethane HC	2	Battery	10		Calibrated in terms of lower explosive limit
lame Ionization	Hydrocarbons (methane equivalent)	14	200 watts	2	0-1, 0-20, 0-100	Requires hydrogen
ual Flame FID	Nonmethane HC	27	110V, 10 amps	15	0-4 up to 0-10000	Required hydrogen
olorimetric	SO_2	34	110V, 1.5 amps	450	0-2	
	NO_2	34	110V, 1.5 amps	750	0-3 (log scale)	
	$NO + NO_2$	34	110V, 1.5 amps	750	0-3 (log scale)	
	Oxidants	34	110V, 1.5 amps	450	0-3 (log scale)	
	SO_2	5	12V	180	0-.5, 0-4	
	NO	5	12V	240	0-.5, 0-4	
	NO_2	5	12V	240	0-.5, 0-4	
V Absorption	NO_2	15	115V	.5 sec + cell flush	0-100	
	NO	15	115V	.5 sec + cell flush	0-100	
	SO_2	15	115V	.5 sec + cell flush	0-100	
envative Spectroscope (D^2)	SO_2 and NO and NO_2 and Ozone	56	110V, 1 amp	72 second scan per pollutant	0-2, 0-12	
hemoluminescence	Ozone	16	Battery, 110V, 2 amp	1 second	0-.5, 0-1, 0-5	Requires ethylene
erosol Formation	Nitrogen Dioxide, SO_2, others	8	Batteries	10	low ppm	

TABLE A-3. (Continued)

Type	Constituent	Weight, kg	Power	Response Time, sec	Range, ppm	Comments
Al_2O_3 Hygometer	H_2O	small	small	30	0-100 pc	
NDIR	CO	29	115V, 2 amps	.5 + cell flush	0-50, 0-500	
	CO_2	29	115V, 2 amps	.5 + cell flush	0-100, 0-500	
	CH_4	29	115V, 2 amps	.5 + cell flush	0-2000	
	N-Hexane	29	115V, 2 amps	.5 + cell flush	0-200, 0-1000	
	NO	29	115V, 2 amps	.5 + cell flush	0-500	
	SO_2	29	115V, 2 amps	.5 + cell flush	0-500	
	Ethylene	29	115V, 2 amps	.5 + cell flush	0-20000	
	H_2O	29	115V, 2 amps	.5 + cell flush	0-15000	

APPENDIX B

SUMMARY OF FAA REGULATIONS OF IMMEDIATE CONSEQUENCE TO MISSION

APPENDIX B

SUMMARY OF FAA REGULATIONS OF IMMEDIATE CONSEQUENCE TO MISSION

91.13 Dropping Objects. No pilot in command of a civil aircraft may allow any object to be dropped from that aircraft in flight that creates a hazard to persons or property. However, this section does not prohibit the dropping of any object if reasonable precautions are taken to avoid injury or damange to persons or property.

91.18 Towing: Other than Gliders. (a) No pilot of a civil aircraft may tow anything with that aircraft except in accordance with the terms of a certificate of waiver issued by the Administrator. (b) An application for a certificate of waiver under this section is made on a form and in a manner prescribed by the Administrator and must be submitted to the nearest Flight Standards District Office.

91.19 Portable Electronic Devices. (a) Except as provided in paragraph (b) of this section, no person may operate, nor may nay operator or pilot in command of an aircraft allow the operation of, any portable electronic device on any of the following U. S. registered civil aircraft: (1) aircraft operated by an air carrier or commercial operator; or (2) any other aircraft while it is operated under IFR. (b) Paragraph (a) of this section does not apply to:

(1) Portable voice recorders
(2) Hearing aids
(3) Haart pacemakers
(4) Electric shavers
(5) Any other portable electronic device that the operator of the aircraft has determined will not cause interference with the navigation or communication system of the aircraft on which it is to be used.

91.33 Powered Civil Aircraft with Standard Category U. S. Airworthiness Certificates: Instrument and Equipment Requirements. (a) General. No person may operate a powered civil aircraft with a standard category U. S. airworthiness certificate in any operation described in paragraph (b) through (f) of this section unless that aircraft contains the instruments and equipment specified therein for that type of operation of FAA approved equivalents thereof.

(b) Visual Flight Rules (Day). For VFR flight during the day, the following instruments and equipment are required·

(1) Airspeed indicator
(2) Altimeter
(3) Magnetic direction indicator
(4) Tachometer for each engine
(5) Oil pressure gauge for each engine using pressure system
(6) Temperature gauge for each liquid-cooled engine
(7) Oil temperature gauge for each air-cooled engine
(8) Manifold pressure gauge for each altitude engine
(9) Fuel gauge indicating the quantity of fuel in each tank
(10) Landing gear position indicator, if the aircraft has retractable landing gear.
(11) If the aircraft is operated for hire over water and beyond power-off gliding distance from shore, a Very pistol, and approved flotation gear readily available to each occupant.
(12) Approved safety belts for all occupants. The rated strength of each safety belt shall not be less than that corresponding with the ultimate load factors specified in the current applicable aircraft airworthiness requirements considering the dimensional characteristics of the safety belt installation for the specific seat or berth arrangement. The webbing of each safety belt shall be replaced as required by the Administrator.

(c) Visual Flight Rules (Night). For VFR flight at night, the following instruments and equipment are required:

(1) Instruments and equipment specified in paragraph (b) of this section
(2) Approved position lights
(3) On large aircraft or when required by the aircraft's airworthiness certificate, an approved anti-collision light system. In the event or failure of any light of the anti-collision light system, operations with the aircraft may be continued to a stop where repairs or replacement can be made without undue delay.
(4) If the aircraft is operated for hire, one electric landing light
(5) An adequate source of electrical energy for all installed electrical and radio equipment
(6) One spare set of fuses, or three spare fuses of each kind required.

(d) Instrument Flight Rules. For IFR flight, the following instruments and equipment are required:

(1) Instruments and equipment specified in paragraph (b) of this section and for night flight, instruments and equipment specified in paragraph (c) of this section.

(2) Two-way radio communications system and navigational equipment appropriate to the ground facilities to be used
(3) Gyroscopic rate-of-turn indicator
(4) Bank indicator
(5) Sensitive altimeter adjustable for barometric pressure
(6) Clock with sweep-second hand
(7) Generator of adequate capacity
(8) Gyroscopic bank and pitch indicator (artificial horizon)
(9) Gyroscopic direction indicator (directional gyro or equivalent).

91.63 Waivers. (a) The Administrator may issue a certificate of waiver authorizing the operation of aircraft in deviation of any rule of this subpart if he finds that the proposed operation can be safely conducted under the terms of that certificate of waiver. (b) An application for a certificate of waiver under this section is made on a form and in a manner prescribed by the Administrator and may be submitted to any FAA office. (c) A certificate of waiver is effective as specified in that certificate.

91.70 Aircraft Speed. (a) Unless otherwise authorized by the Administrator, no person may operate an aircraft below 10,000 feet MSL at an indicated airspeed of more than 250 knots (288 mph). (b) Unless otherwise authorized or required by ATC, no person may operate an aircraft within an airport traffic area at an indicated airspeed of more than: (1) In the case of a reciprocating engine aircraft, 156 knots (180 mph); or (2) In the case of a turbine-powered aircraft, 200 knots (230 mph). However, if the minimum safe air speed for any particular operation is greater than the maximum speed prescribed in this section, the aircraft may be operated at that minimum speed.

91.71 Acrobatic Flight. (a) No person may operate an aircraft in acrobatic flight:

(1) Over any congested area of a city, town, or settlement
(2) Over an open air assembly of persons
(3) Within a control zone or Federal airway
(4) Below an altitude of 1,500 feet above the surface; or
(5) When flight visibility is less than three miles.

For the purposes of this paragraph, acrobatic flight means an intentional maneuver involving an abrupt change in an aircraft's attitude, an abnormal attitude, or abnormal acceleration, not neccessary for normal flight.

(b) Unless each occupant of the aircraft is wearing an approved parachute, no pilot of a civil aircraft, carrying any person (other than a crewmember) may execute any intentional maneuver that exceeds (1) a bank of 60 degrees relative to the horizon; or (2) a nose up or nose down attitude of 30 degrees relative to the horizon.

<u>91.73 Minimum Safe Altitudes: General</u>. Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

(a) Anywhere. An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.

(b) Over congested areas. Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.

(c) Over other than congested areas. An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In that case, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

(d) Helicopters. Helicopters may be operated at less than the minimums prescribed in paragraph (b) or (c) of this section if the operation is conducted without hazard to persons or property on the surface. In addition, each person operating a helicopter shall comply with routes or altitudes specifically prescribed for helicopters by the Administrator.

<u>91.95 Restricted and Prohibited Areas</u>. (a) No person may operate an aircraft within a restricted area (designated in Part 73) contrary to the restrictions imposed, or within a prohibited area, unless he has the permission of the using or controlling agency, as appropriate. (b) Each person conducting, within a restricted area, an aircraft operation (approved by the using agency) that creates the same hazards as the operations for which the restricted area was designated, may deviate from the rules of this subpart that are not compatible with his operation of the aircraft.

91.97 Positive Control Areas and Route Segments. (a) Except as provided in paragraph (b) of this section, no person may operate an aircraft within a positive control area or positive control route segment, designated in Part 71 of this chapter, unless that aircraft is

(1) Operated under IFR at a specific altitude assigned by ATC
(2) Equipped with instruments and equipment required for IFR operations:
(3) Flown by a pilot rated for instrument flight; and
(4) Equipped, when in a positive control area, with:
  (i) A coded radar beacon transponder, having at least Mode A (military Mode 3) 64 code capability, replying to Mode 3/A interrogation with the code specified by ATC; and
  (ii) A radio providing direct pilot/controller communication on the frequency specified by ATC for the area concerned.

(b) ATC may authorize deviations from the requirements of paragraph (a) of this section for operation ina positive control area. In the case of failure of a radar beacon transponder, ATC may immediately approve operation within a positive control area. In all other cases, request for an authorization to deviate must be submitted at least four days before the proposed operation, in writing, to the ATC center having jurisdiction over the positive control area concerned. ATC may authorize deviations on a continuing basis or for an individual flight, as appropriate.

91.105 Basic VFR Weather Minimums. (a) Except as provided in §91.107, no person may operate an aircraft under VFR when the flight visibility is less, or at a distance from clouds that is less, than that prescribed for the corresponding altitude in the following table:

Altitude	Flight Visibility	Distance From Clouds
1,200 feet or less above the surface (regardless of MSL altitude)--		
Within controlled airspace.	3 statute miles	(500 feet below. (1,000 feet above. (2,000 feet horizontal.
Outside controlled airspace.	1 statute mile except as provided in §91.105 (b)	Clear of clouds.

(Continued on next page)

C-2

Altitude	Flight Visibility	Distance From Clouds
More than 1,200 feet above the surface but less than 10,000 feet MSL--		
Within controlled airspace.	3 statute miles	(500 feet below. (1,000 feet above. (2,000 feet horizontal.
Outside controlled airspace.	1 statute miles	(500 feet below. (1,000 feet above. (2,000 feet horizontal.
More than 1,200 feet above the surface and at or above 10,000 feet MSL.	5 statute miles	(1,000 feet below. (1,000 feet above. (1 mile horizontal.

(b) When the visibility is less than one mile, a helicopter may be operated outside controlled airspace at 1,200 feet or less above the surface if operated at a speed that allows the pilot adequate opportunity to see any air traffic or other obstruction in time to avoid a collision.
(c) Except as provided in §91.107, no person may take off or land an aircraft, or enter the traffic pattern of an airport, under VFR, within a control zone--(1) Unless ground visibility at that airport is at least 3 statute miles; or (2) If ground visibility is not reported at that airport, unless flight visibility during landing or takeoff, or while operating in the traffic pattern, is at least 3 statute miles.
(e) For the purposes of this section, an aircraft operating at the base altitude of a transition area or control area is considered to be within the airspace directly below that area.

APPENDIX C

SPECTROSCOPIC INSTRUMENTS

APPENDIX C

SPECTROSCOPIC INSTRUMENTS

This broad class of instrumentation has the unique ability to "optically sample" gases without the complications of physical sample extraction. Thus, measurements can be made without introducing errors (which can be significant*) due to chemical and physical reactions in the sample train.

In order to discuss the merits and deficiencies of spectroscopy for the proposed mission, it is first necessary to expand upon the current spectroscopic techniques. Reference 36 discusses several techniques which show promise:

> Laser Raman Spectroscopy--wherein the coherent beam from a UV laser interacts with the gaseous molecules. A very small fraction of the radiation is scattered by the interacting molecules at frequency displaced from the incident frequency by a increment corresponding to the characteristic molecular vibration of the interacting molecules.
>
> Laboratory analysis instruments using Raman scattering are operable. Signal to noise ratios can be greatly improved by using time-gated detection rather than continuous detection.
>
> The technique could be used for simultaneous multicomponent analysis. However, the state of the art in Raman spectroscopy yields equipment which is complex, expensive, and technically involved to operate. Also, the presence of hydrocarbons causes interferences due to fluorescent emissions of some species in the UV range.

---

* An error of a factor of 1.5 to 5 can be inferred from results of experiments using narrow line UV absorption[37] versus a conventional sampling rake and NDIR[38].

Near-Resonance Raman Spectroscopic differs from the above in that the frequency of the laser source is selected to be slightly different than that of a strong absorption band of the species of interest. Theory suggests that the scattered radiation should be several orders of magnitude larger than that of nonresonant scattering. However, the ability to simultaneously perform multicomponent ananysis is lost.

Resonant Absorption--This technique takes advantage of unique resonant absorption bands of the species of interest. The radiation to be absorbed could be provided by a black body with a monochromator, by a tuned semiconductor laser, or by a tuned gaseous laser. In the former approach, there is interference by atmospheric water vapor at frequencies near the absorption band. The very narrow spectral range of either laser source, however, enables the avoidance of this problem.

In a recent review of the state of the art[39], it was concluded that semiconductor laser absorption is an effective technique, but the applications of the technique have been limited by the expertise required to manufacture the semiconductor lasers themselves. Hence, this technique, although attractive, is not yet an "off-the-shelf" item.

The Diax Corporation[40] is developing a gaseous laser system for measuring atmospheric pollutants. This instrument will use an opto-acoustic detector for the reception of the absorption modified beam. It will be programmable to analize up to 20 compounds. The instrument is not currently available.

Dispersive Mechanical Correlation Spectroscopy--A segment of the absorption spectrum of a sample scanned across a mechanical mask, designed such that its openings correspond to resolved spectral bands of the specie to be measured. The signal amplitude fluctuation during the scan is related to the concentration of the specie.

This technique is currently available for several species. In principal, it is possible to construct an instrument for simultaneous multi-component monitoring.

Nondispersive Optical Correlation--In this technique, the absorption of an IR beam by a sample in a cell is compared to the absorption of the same beam in a reference cell containing a known concentration of the specie of interest. The difference of the absorptions provides the concentration of the species of interest. In this technique a physical sample of the gas must be taken.

Interferences can be screened out by the use of IR filters. Alternately, introduction of the interfering species at a sufficiently high concentration into both cells effectively eliminate the interference.

This technique has been used for over 30 years in analysis of gases. Hence, there are many instruments commercially available for single component analysis. A simultaneous three-component analysis instrument has been demonstrated[41].

Fourier Transform Interference Spectrophotometry--In this technique, the frequency dependent absorption spectrum is mapped, via mechanical interferometry, into a time varying signal. The interferogram may be inverted via Fourier transforms to an absorption spectrum which may be subsequently compared, by the use of a computer to spectra resulting from specific species. In this manner, the concentrations of all compared species may be statistically derived from the signal.

The instrument and the computer analysis are both expensive. In addition, the spectral resolution is generally not fine enough to avoid water vapor interference. Finally, the accuracy of available instruments is far less than that of NDIR.

Derivative Spectroscopy--In this technique, the signal resulting from an optical scan of a sample is the first or second derivative of the absorption spectrum with respect to frequency. This technique can result in a signal to noise ratio larger than that of the original absorption spectrum. Unfortunately, fluroescent emissions of hydrocarbons in the IR range have been shown to obscure the derivative signal.

Reference 42 presents some of the spectroscopic instrumentation which, although not commercially available, have been or are nearly constructed into engineering models. These include

Name	Type	Species
COPE	Correlation Interferometry	CO, CH_4
CIMATS	Correlation Interferometry	Many
DARS	Differential Absorption	CO, NO, CH_4
GFCI	Gas Filter Correlation	CO
GFCI	Gas Filter Correlation	SO_2
MAPS	Gas Filter Correlation	6 gases
HSI	Interference Spectrometry	Many

In principle, any of these instruments could be used over a closed, short path with an artificial radiation source.

As an IR scanning system (irdicon) will be recommended for monitoring the position of the cloud from the ground, attention was given to the possibility of obtaining species concentrations from the IR signal. Some models of scanning IR devices do allow the automatic sequencing of upwards of eight IR spectral filters, so the equipment for the procedure is off-the-shelf.

The energy recorded by the IR irdicon is affected by scattering and by wavelength dependent emission and absorption effects. Of course, the primary purpose of the irdicon is to record the IR emissions of the warmer than ambient ground cloud, so as to allow a post-test triangulation of its position. As a result, the cloud should not fill the entire field of view of the sensor, and, thus, radiation undisturbed by the cloud will also be recorded.

The addition of spectral filters to the irdicon for absorption wavelengths of the species of interest will provide information of the relative optical thickness of the cloud for each species. This in turn could be correlated to the measurements made by the sampling platform. The resulting data might be useful in filling the details of the cloud structure.

TABLE C-1. INFRARED CAMERA SYSTEM CHARACTERISTICS

	AGA Thermovision System 680	Barnes Infrared Camera Model T-101/T-102	DYNARAD Fast Scan Infrared Thermal Imaging Systems Model 209	Spectrotherm Model 800
Frames/Second	16	2 or 4	60, 30, 15	0.5
Lines/Frame	210	160 or 95	100, 200, 400	580
Picture Elements Line		224	100	600
Temperature Range	-30° to 850°C (to 2000°C by filters)	-20° to 150°C (to 1500°C by slides)	-20° to 150°C (to 2000°C by Aperature plates)	-20° to 420°C
Minimum Detectable Temperature	<0.2°C @ 30°C	<0.1°C @ 30°C	0.5°C	0.2°C rms
Picture Temperature Range	10 sensitivity steps and 7 f/stops	1°C to 150°C in 6 gain steps		
Isotherm Functions	Dual or Single	Dual or Single	Dual or Single	NO-Profile Scan
Isotherm Widths	Variable width, levels adjustable continuously and independently	Variable width Adjustable from 2.5 to 20 pc range	Variable width Adjustable from 2-20 pc range	NO
Field of view	10° x 10°	25° x 12.5° (and 12.5° x 12.5°)	10° x 10°	30° x 30°
Detector Spectral Range	2.0 to 5.6μ	1.0 to 5.5μ	2.0 to 5.6μ	
Filtering	Up to 8 in. wheel	Changeable	Up to 8 in. wheel	
Visual Display Picture Size	3.5 in. x 3.5 in. (2.7 in. x 2.9 in. photo)	2.5 in. x 1.25 in. and 2.5 in. x 2.5 in.	(3" x 3")	3" x 4"
Mode Options	Image, Image with Isotherms, Inverted with Isotherm, Image Suppression or Elimination, profile (Isometric)	Image, Image with Isotherms, Inverted with Isotherm, Image Suppression or Elimination, Single Line Scan	Image, Image with Isotherms, Single Line Scan, Isometric	Frame Freeze
Optional Output	Magnetic tape, not readily convertible to video tape output, extra monitor	Digital magnetic tape, reconstructed video option	Video tape record option	Polaroid, 70-mm film Standard TV video tape
Price	$28,000	$18,000	$17,900	$33,600

APPENDIX D

AUXILIARY DATA

APPENDIX D

AUXILIARY DATA

Cables

There are a number of characteristics which must be considered when selecting a cable. These include high tensile strength, high strength-to-weight ratio, low drag, low stretch, torque stability, high flexibility, abrasion resistance, and of course low cost. Table D-1 compares the primary physical characteristics for a number of leading cable materials. It is apparent from this table that any 1,000 ft cable capable of supporting a few thousand pounds of payload will weigh less than 40 pounds. Figure D-1 is also provided to show the strength to cost ratio for these fabrics. These data were obtained from a 1968 report.

Winches

A list of many of the U. S. winch manufacturers is listed in Table D-2, along with the operational characteristic of various models. The table is provided merely to represent typical characteristic of generic systems. The table shows that winches weighing in the neighborhood of 300 pounds are typically capable of vertically moving a 750-lb payload a distance of 1500 ft. Unfortunately, line speeds are limited to about 200 ft/min, and so 7 or 8 minutes are required to unreal 1500 ft of cable. A few winches have a greater line speed; these systems also tend to be heavier. For example, Model No. 82 by All American has a line speed of 1440 ft/min. The payload is 800 lb, weight 324 lb, and dimensions 38-1/4 x 30 x 24-1/2.

Power must be supplied to the payload. If the power source is in the helicopter, then a power cable must be lowered coincident with the payload. This will be difficult especially if the payload is lowered at a high line speed. A second alternate is to have a power supply with the payload, in the form of a battery.

TABLE D-1. COMPARISON OF TETHER MATERIALS

Cable Material	Construction	Weight, lb/ft	Strength, pounds	Diameter, inches
S-Glass Monostrand	Single strand	0.0094	3000	0.125
E-Glass Glastran	1 x 7	0.0095	1800	0.128
Samson 2-in-1 Nylon	Braided	0.0166	2100	0.250
Carbon Rocket Wire	1 x 19	0.0310	3275	0.117
Music Wire	1 x 19	0.0360	3250	0.121
NS-355 Stainless Steel	7 x 19	0.0296	2370	0.138
Dacron Nolaro	No-lay	0.0210	1650	0.250
Type 340 Stainless Steel	3 x 7	0.0402	2800	0.1562
NS-302 Stainless Steel	7 x 19	0.0290	1960	0.236
Mylar Rope	Three-strand	0.0213	1400	0.125

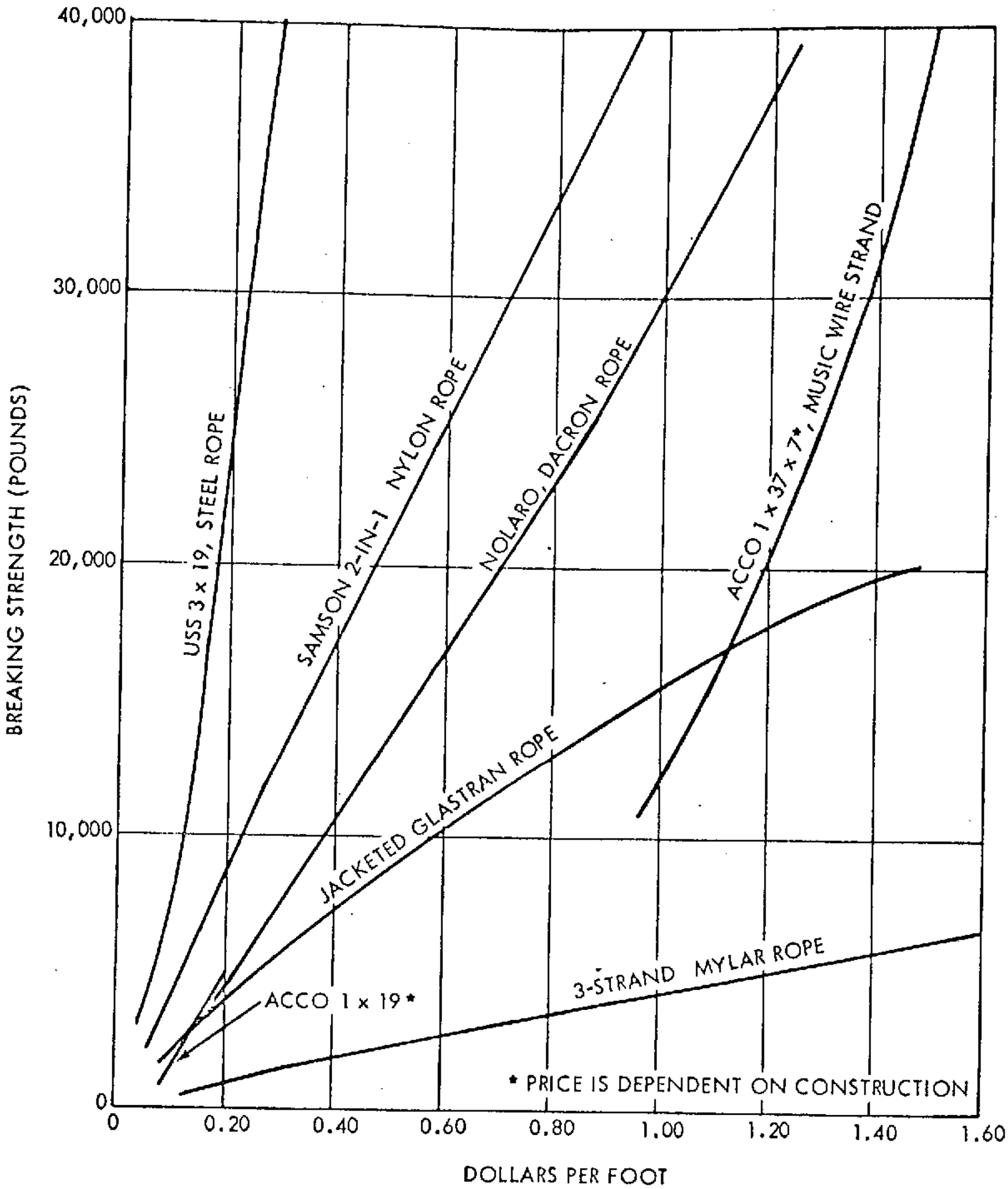

FIGURE D-1. STRENGTH-TO-COST RATIOS FOR VARIOUS CANDIDATE BALLOON TETHERS (1968 Data)

TABLE D-2. AVAILABLE WINCHES

Manufacturer	Model Designation	Type of Power	Power Rating (hp)	Overall Size (inches)			Approx Weight (lb)	Drum Size (inches)			Cable Storage Capacity		Load Capacity (lb)	Line Speed (ft/min)
				Length	Width	Height		Drum	Flange	Length	Length (ft)	Dia (in.)		
King	130	Gas	3.0 at 3600 rpm	25	23	23	160	4	12	16	1,860	1/4	300	200
	240	Gas	4.0	35	23	36	270	4	12	20	1,950	1/4	400	200
	260	Gas	6.0	35	23	36	280	4	12	20	1,950	1/4	550	200
	364	Gas	6.0	42	29	41	320	4	14	18	2,700	1/4	600	200
	380	Gas	8.0	42	29	41	360	4	14	18	2,700	1/4	750	190
	480	Gas	8.0	48	35	41	385	5	16	20	4,700	1/4	725	180
	490	Gas	9.0	48	35	41	398	5	16	20.	4.700	1/4	850	180
	530	Gas	3.0	24	24	30	160	4	12	16	1,950	1/4	400	160
	540	Gas	4.0	24	24	30	165	4	12	16	1.950	1/4	525	180
	560	Gas	6.0	31	28	32	295	7	13	12	1,500	1/4	600	225
	568	Gas	8.0	31	28	32	315	7	13	12	1,500	1/4	750	200
	580	Gas	8.0	36	28	32	365	7	16	12	2.400	1/4	850	200
	590	Gas	9.0	36	28	32	380	7	16	12	2.400	1/4	1,000	200
	703	Elec	3.0	36	28	17	415	7	15-1/2	12	2,200	1/4	850	100
	705	Elec	5.0	54	31	30	1,480	7	16	16	1,500	3/8	1.100	100
	707	Elec	7.5	56	31	30	1,530	7	16	16	1,500	3/8	1,700	100
	710	Elec	10.0	60	33	34	1.575	7	16	16	1,500	3/8	2,150	100
	803	Elec	3.0	38	23	19	400	7	16	12	1.100	3/8	1,200	50
	805	Elec	5.0	38	23	19	550	7	16	12	1,100	3/8	2,000	50
	807	Elec	7.5	42	31	30	700	7	16	12	1,100	3/8	3,200	50
	810	Elec	10.0	42	31	30	1,200	7	16	12	1,100	3/8	3,700	50
	1220	Gas	10.9 at 2400 rpm	48	36	34	1,050	7	16	16	1,500	3/8	2,000	130
	1835	Gas	16.4 at 2600 rpm	48	36	35	1,350	7	16	16	1,500	3/8	3,500	122
	2560	Gas	26.5 at 2200 rpm	50	40	42	2,300	10	16	16	1,200	5/8	6,000	115
	3455	Gas	34.0 at 2000 rpm	72	52	42	2,600	10	16	16	1,200	5/8	5,500	160
	6060	Gas	53.8 at 2200 rpm	84	52	42	3,000	12	24	16	1,150	5/8	6,000	233
R.G. LeTourneau	BW-30 Balloon winch vehicle	Diesel	---	387	153	159	72.500	---	---	---	1,400	3/4	26,000	100
	W-500	Elec	---	84	44	70	8,000	---	---	---	1,200	1-1/2	50,000	20
Markey	DW-5980 Oceanographic	Elec	25	89	74	---	8.000	12	30	24	30,000	3/16	1.500	Up to 600
Otis Engr	82MO136	Diesel	47	80	28	49	2.400	---	---	---	25,000	0.082	2.675	60
	82MO151	Diesel	47	69	60	48	2.400	---	---	---	25,000	0.082	2.675	60
	82MO23	Diesel	52	86	72	48-1/2	3,700	---	---	---	25,000	0.082	3,500	10
	82MO222 and -223	Diesel	34	Two separate units			2,100	---	---	---	18,500	0.082	1.150	10
	Special purpose unit	Diesel	30	Two separate units			1.300	---	---	---	---	---	---	---
	82MO271 and -193	Diesel or hyd	80	Two separate units			---	---	---	---	17,000	3/16	6.000	10
	82MO200 and -193	Diesel or hyd	80	Two separate units				---	---	---	17.000	3/16	---	---
Sasgen	SDL-15-A-8	Gas or elec	8 to 11	---	---	---	735 to 775	6	---	14	450	1/2	1.500 to 2,000	125 to 150
	SDL-20-A-11													
	SDL-17-A-11													
	SDM-26-R-20	Gas or elec	15 to 20	---	---	---	770 to 1,300	6	---	14	1,250	3/8	2,000 to 2,600	150 to 200
	SDM-23-R-20													
	SDM-20-R-20													
Silent Hoist	TA15C	Elec	15	---	---	---	---	---	---	---	---	---	12,000	30
	WA-30AC	Elec	30	---	---	---	---	---	---	---	---	---	24,000	30
	FHA-50AC	Elec	50	---	---	---	---	---	---	---	---	---	40,000	30
	TE15AC	Elec	15	---	---	---	---	---	---	---	---	---	12,000	30
	FHE-50AC	Elec	50	---	---	---	---	---	---	---	---	---	40.000	30
Skagit	BU-6	Gas	---	67 to 106	60 to 79	36 to 67	1,500 to 6,800	7-1/2 to 13	15 to 30	15 to 20	665 to 1,250	1/2	---	---
	BU-12	Diesel												
	BU-15	Hyd or elec												
	BU-16													
Smith-Berger	Ground handling	Elec	---	50	42	36	---	10	18	20	400	3/4	---	50
	Upper balloon winch	Elec	200	284	96	---	---	20	50	25	16,000	3/8	10,000	Up to 400
	Lower balloon winch	Elec	300	384	96	---	---	30	64	25	12,500	5/8	22,800	Up to 400